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NUTRIENT DEFICIENCIES AND FERTILISER USE IN NEW ZEALAND EXOTIC FORESTS

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PREFACE

This Bulletin has been prepared as a practical guide to the identification and correction of nutrient deficiencies: primarily for radiata pine although some information is provided on eucalypts. Over the last 30 years, nutrient deficiencies have been identified in various forests throughout New Zealand, and measures have been developed to correct them. These have been reported in a variety of publications, many of which are now not readily available to forest managers.

This publication brings together under one cover a summary of current information. Its purpose is to aid those involved in plantation forestry in New Zealand. It should be used to:

Help identify nutrient deficiencies;

Formulate fertiliser applications to correct them.

In most situations where severe deficiencies markedly restrict growth, the cost of fertiliser application will undoubtedly give a good financial return. Where deficiencies are marginal, the local forest manager must assess for himself the balance between the cost of applying fertiliser in his forest and the volume, quality, and value of the extra wood that will be produced.

It is planned that this Bulletin will be updated in the future to include the results of current research. This includes the use of rock phosphates, more specific details on eucalypts, and some work with *Acacia melanoxylon* and *Cupressus* spp.

While preparing this Bulletin, I was repeatedly reminded of the large number of people who have contributed to the present state of our knowledge. I am indebted to research workers from other countries (particularly Australia) who have shared their experience. Within New Zealand a great number have played significant roles– both in the field and in the laboratory. It is not possible to list, or even remember everyone, but I wish to acknowledge the particular contributions made by the following: Russ Ballard, Russ Fitzgerald, Ruth Gadgil, Doug Graham, Helge Holstener-Jorgensen, Ian Hunter, Harry Jacks, Peter Knight, Don Mead, Earl Stone, and Graham Weston.

1. GENERAL INTRODUCTION

Use of Fertilisers in New Zealand Forests

During and after the large-scale establishment of radiata pine plantations in New Zealand in the 1920s and 1930s, very little consideration was given to their nutrition. Pines were thought of as pioneer plants that could be expected to grow successfully on infertile soils. As early as 1932, however, ill thrift in the form of fused needles was reported for pines growing in Riverhead Forest. The condition of trees over considerable portions of the forest gave increasing cause for concern, but it was not until 1952 that field fertiliser trials were established in unthrifty stands.

Stimulated by results achieved in Australia, superphosphate and zinc fertilisers were applied and within 1 year dramatic improvements in foliage vigour were visible in the superphosphate-treated plots. This was followed by some quite spectacular increases in tree diameter growth (Fig.1.). No responses to zinc were evident.

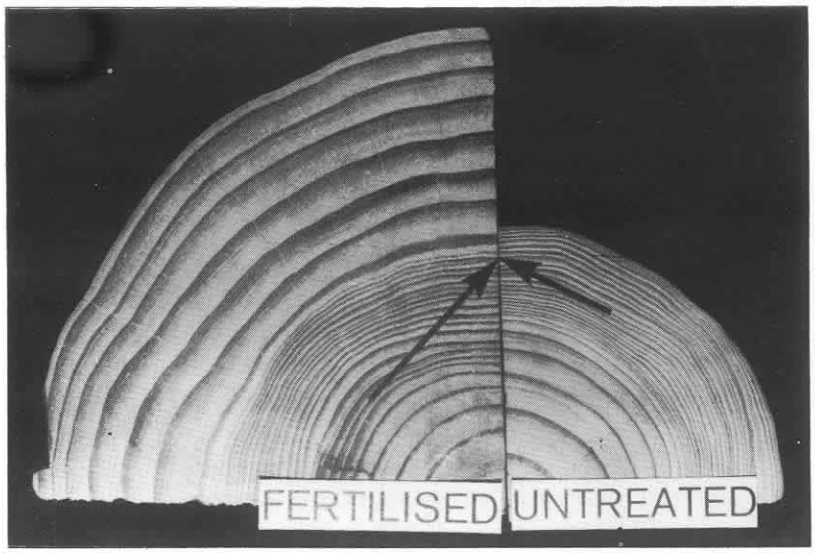

FIG.1 Diameter growth response to 250 kg P/ha applied as superphosphate 8 years before felling (arrows indicate diameter at time of application). Note persistence of fertiliser effect. (BW 76802)

These results soon led to fertiliser applications on a management scale in Riverhead, Maramarua, and other forests where tree growth was affected by phosphorus deficiency. They also led to a reappraisal of the nutrient health of plantations throughout the country and the opportunities that might exist for the profitable use of fertilisers.

Following the identification of phosphorus deficiency and its successful correction by fertilisers, deficiencies of nitrogen, magnesium, boron, copper, and potassium have in turn been identified and are now routinely corrected by fertilisation. However, nitrogen, phosphorus, and boron are the big three in forest fertilisation in New Zealand in terms of areas treated and quantities of fertiliser used.

While routine fertiliser applications began in the late 1950s, it was not until the 1970s that substantial and increasing amounts of fertiliser were applied each year. Between 1970 and 1980 the annual use of fertilisers in forests increased 10-fold. In the last 3 years, however, there has been only a slight increase in the area treated each year. In 1980 just over 30 000 ha had fertiliser applied to them and in 1983 the area was 34 600 ha (Table 1). About half of this area was established forests, all of which were treated from the air.

While the total area to which fertilisers have been applied has remained stable over recent years, Fig.2 shows that in 1983 there was an appreciable drop in the amount of nitrogen applied. There have also been changes in the types of fertilisers used. Table 2 gives details of a marked increase in the use of diammonium phosphate (DAP), which resulted in it becoming the major source of both nitrogen and phosphorus. It should also be noted that triple superphosphate has largely replaced single (ordinary) superphosphate. Triple superphosphate only became widely available in 1983 but this well-granulated (dust-free), high-analysis fertiliser is ideal for both hand application at time of planting and aerial topdressing.

In 1979 the New Zealand Forest Service adopted a Fertiliser Policy which distinguished between using fertilisers to (1) correct visible nutrient deficiencies in trees and (2) increase the growth rate of apparently healthy trees. Type 1 situations are required to be fertilised as a matter of routine but the use of fertilisers to achieve increased production in healthy stands is decided on the basis of an economic assessment. This approach is now widely used throughout the forest industry. In general, the steady amounts of phosphorus and increased amounts of boron used in the last few years reflect routine use in Type 1 situations. The reduction in nitrogen use is largely a result of Type 2 economic re-evaluation in a period of recession.

TABLE 1 – Forest areas (ha) fertilised in 1983 in New Zealand

Region	At establishment	Older stands	Total*
North Island			
Auckland	8 078	7 154	20 589
Rotorua	1 287	2 830	4 218
Wellington	199	322	1 053
Total	9 564	10 306	25 860
South Island			
Nelson	534	1 763	2 320
Westland	1 354	3 266	4 647
Canterbury	12	1 315	1 360
Southland	139	274	413
Total	2 039	6 618	8 740
OVERALL TOTAL	11 603	16 924	34 600

Total areas for Auckland and Wellington also include marram grass areas fertilised.

TABLE 2 – Fertiliser sources used in New Zealand forestry in 1975, 1980, and 1983 (%)

Source	1975	1980	1983
Nitrogen			
Urea	82	71	36
DAP	7	12	47
Others	11	17	17
Phosphorus			
Super	88	67	14
DAP	8	23	45
Triple super	0	0	36
Others	4	10	5

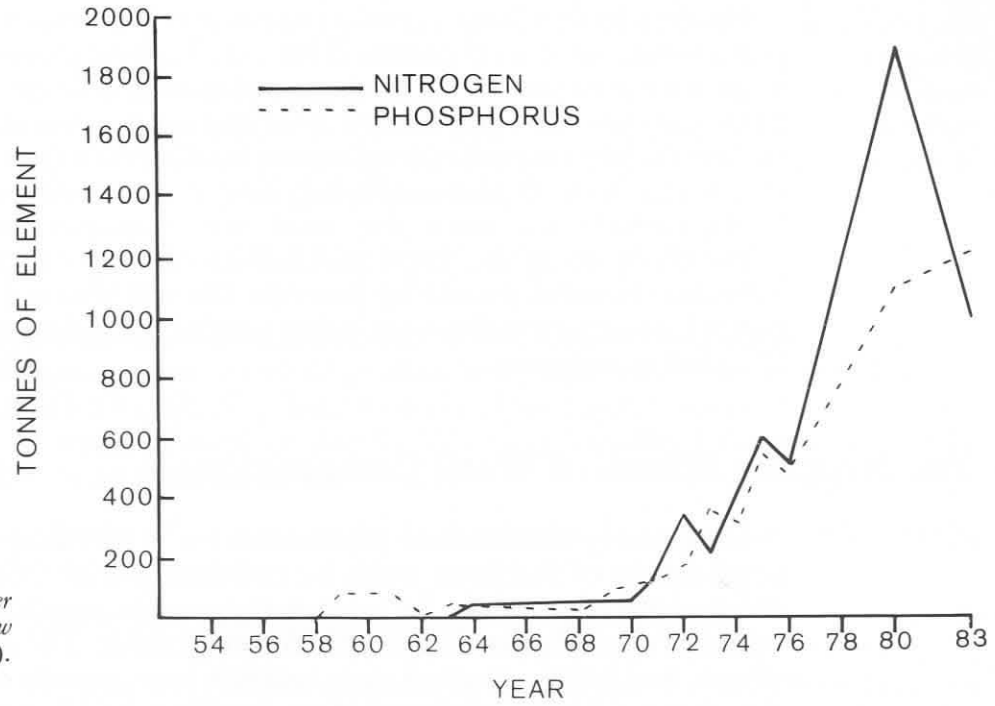

FIG.2 Quantities of fertiliser elements used annually in New Zealand forestry (1954-83).

What Effects do Pines Have on the Soil?

For over half a century there have been accusations that pines degrade the soil in which they are growing. As early as 1914 it was reported in the New Zealand Journal of Agriculture, "There is a widespread belief that *Pinus radiata* is a great soil exhauster and that soil once occupied by this tree becomes very infertile". In a 1976 newspaper report a prominent scientist was quoted as saying, "Many believe with very good reason that the growth of pines in pure even-aged stands is responsible for a permanent deterioration of the soil".

Field evidence does not substantiate such extravagant and often emotional claims, which continue to be made not only in New Zealand but in international circles. Soil acidification and podzolisation are amongst the undesirable processes said to be promoted by pines. However, these processes occur to a greater degree under many of our native trees, particularly kauri.

It must be stressed on the other hand that the frequent harvesting of crops of fast-growing species inevitably results in the removal of appreciable quantities of nutrients. With whole tree harvesting, nutrient removal would be even greater and could approach that of some forms of agricultural land use. Sooner or later, the nutrient removal associated with the harvesting of fast-growing plantations will cause nutrient depletion in a soil and lower productivity. Application of an appropriate fertiliser will be then required to restore full productivity.

Comparisons with Agriculture

Many forest plantations in New Zealand have been established on soils which have either been rejected for agricultural use or later abandoned. While other factors such as drainage and erosion are sometimes involved, many decisions in favour of afforestation have been made on the basis of a soil's inherent infertility for agricultural purposes and the uneconomic fertiliser input needed to sustain productivity.

Healthy pine foliage contains lower levels of nutrients than the leaves of common agricultural plants. This and the evergreen nature of pines that requires only a partial replacement of canopy foliage each year means that, after canopy closure, annual nutrient requirements are relatively low. However, the extensive need to use fertilisers in first-rotation plantations on certain New Zealand soils is evidence that their inherently low fertility is inadequate for even the moderate requirements of pines. This is particularly so in the years just before canopy closure. At this time, the nutrient demand placed by trees on the soil reaches a peak as maximum quantities of new foliage are being produced and nutrient cycling through litterfall is minimal.

The Negative Effects of Weed Competition

In a newly established plantation on a fertiliser-responsive site, the application of fertiliser must be combined with effective control of any competing vegetation. In most instances the application of fertiliser will stimulate weed growth more than tree growth. The resulting competition above and below ground may restrict tree growth to a level below that which would have occurred if no fertiliser had been applied.

When fertilisers are allowed to promote unrestricted weed competition, trees can be adversely affected in one or more of three ways (Fig.3):

(i) above-ground competition for space and light;

(ii) below-ground competition for nutrients– both those contained in the fertiliser and those naturally in the soil;

(iii) below-ground competition for moisture.

While the above-ground competition is mostly easily seen and counteracted, the below-ground competition is often the most damaging in terms of poor survival and reduced growth.

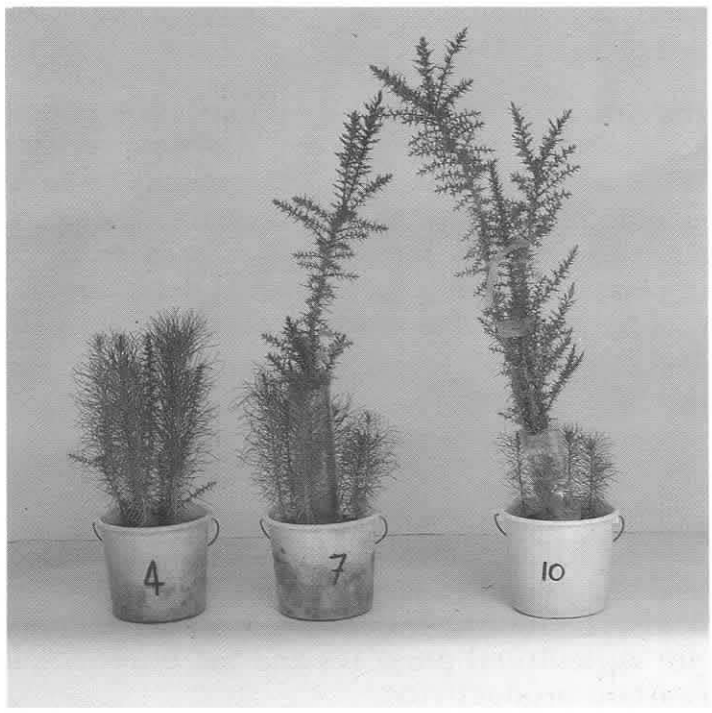

FIG.3 Pot trial with radiata pine and gorse in an infertile Nelson soil (Mapua sandy loam). From left to right: no fertiliser; phosphorus only; and phosphorus + boron + molybdenum. Note the suppression in growth of the radiata pine as the gorse responded to the addition of fertiliser. The effect of competition in the field can be just as dramatic.

How to Decide when Fertilisers are Needed

Ideally, fertilisers should be applied before growth is restricted, i.e., before any visual effects of a deficiency are present. In agriculture and horticulture, soil tests are used extensively to estimate types and rates of fertiliser that are required to ensure that nutrient deficiencies do not restrict plant growth. These tests, developed and calibrated to assess the short-term soil requirements for relatively shallow-rooted agricultural crops, are of very limited use in forestry. Apart from nurseries, where agricultural soil tests have direct application, only one test has been found to be of practical use in the field. This is the Bray-2 test for phosphorus. If an unplanted site tests at less than 9 ppm Bray extractable phosphorus, it indicates that phosphate fertiliser will probably be required soon after planting pines.

Once a crop of pine trees has been established on a site, foliage analyses have proved a reliable method of identifying existing and developing nutrient-deficient conditions which require correction by the application of fertilisers.

Although foliage analysis is a proven and reliable method of identifying stands in need of fertiliser, it should not be the sole input into management decision-making. Decisions on when to apply fertiliser should also be made on the basis of past experience and local knowledge (soil types and their boundaries, past fertiliser use, etc.). Foliage analyses should be used to confirm that correct decisions are being made and to monitor the effectiveness of fertiliser applications.

How to Apply Fertilisers

(1) *In the year of planting:* To minimise stimulation of competing vegetation, the fertiliser should be localised close to but not in contact with tree roots. In routine operations, this is achieved by placing the fertiliser in a spade slit 10–15 cm from the base of each tree. Even with some so-called slow-acting fertilisers, care must be exercised to ensure that the roots of newly planted trees do not come into direct contact with a concentrated dose of fertiliser.

(2) *Established stands:* With very few exceptions, aerial spreading is the only practical means of applying fertiliser which must also be evenly distributed. Greatly improved distribution has been achieved in recent years through the use of well-granulated (dust-free) fertilisers applied from aircraft fitted with an electronic guidance system.

The Fate of Nutrients Applied as Fertilisers

It is unusual for a major proportion of any nutrient in a fertiliser to be taken up by a forest plantation (or any plant crop). Even if there is no uptake by competing weeds, chemical changes in the soil often reduce the availability of nutrients. Water-soluble phosphates react with the clay, and with iron and aluminium compounds in many acid soils, to greatly reduce the amounts available in the short term for plant uptake. Nitrogen may be lost from some fertilisers by volatilisation of ammonia or conversion to nitrate, which leaches rapidly from the soil. Such reactions make it necessary to repeat fertiliser applications after a period of time and to apply more of a nutrient than the tree crop itself requires.

Once in the tree, nutrients react in different ways. Potassium washes from foliage and litter very readily and is quickly recycled. Phosphorus cycles in a similar, but slower, manner. Nitrogen is not easily washed from foliage, and litter decomposition proceeds for several years before much nitrogen is released. On the other hand, all three of these nutrients are cycled within the tree from old foliage and wood to new tissues. In contrast, boron and calcium are not significantly relocated within a tree and input into new tissues is largely from direct uptake by the roots.

Visual Identification of Nutrient Deficiencies in Radiata Pine

Specific details are given for individual nutrients in later sections but some general guidelines should be emphasised.

(a) Symptoms of soil nutrient deficiencies usually occur evenly in a group of trees. A single tree affected by, for example, nitrogen deficiency is often a result of disease, animal, or mechanical damage restricting nitrogen uptake into the tree crown rather than a soil deficiency of nitrogen.

(b) Within a tree crown, nutrient deficiency symptoms occur in a regular and predictable pattern. One branch in a whorl or side of a tree is not affected more than the others. One needle fascicle is not affected substantially more than its immediate neighbours. All needles in a fascicle are affected to a similar degree.

(c) Fused-needle symptoms can be associated with deficiencies of phosphorus, boron, and copper.

(d) Excessive twisting is associated with copper deficiency and (Australian experience suggests) to a lesser extent with potassium and perhaps boron deficiencies. However, branch twisting can often be caused by severe wind and rain during periods of rapid shoot elongation.

(e) Boron deficiency is characterised by shoot and bud dieback. Deficiencies of certain other nutrients, e.g., calcium, can cause dieback but only in extreme circumstances unlikely to be often encountered in the field.

(f) Discoloration of pine foliage is largely restricted to one of several types of chlorosis (yellowing). The types can be distinguished as follows:

(i) *Nitrogen deficiency*
Uniform chlorosis over whole tree – but there may be a greener tuft on leader. Needles short and uniformly yellowish green over whole length.

(ii) *Phosphorus deficiency*
Yellow needle-tips in current year's foliage from midsummer on. In young trees, symptoms are most noticeable in lower crown. Yellow tipping increases towards end of shoots and is often associated with abnormally short needle length.

(iii) *Magnesium deficiency*
Golden yellow needle-tips in last year's foliage in mid-upper part of crown. Most obvious in the spring when current season's shoot extension is at a peak.

(iv) *Potassium deficiency*
Similar to magnesium deficiency but developing earlier in the year, most obvious in mid-lower crown, and chlorosis is a true yellow rather than "golden".

Chlorotic foliage can also be caused by fungal attacks and herbicide damage: in both cases, symptoms tend to be much less regular than with nutrient deficiencies. A fungal attack commonly affects one needle in a fascicle more than the others, and adjacent fascicles may be affected to quite different degrees (Fig.4). Chlorosis caused by herbicides may also be irregular in its distribution in a tree crown: adjacent branches may be affected to very different degrees (Fig.5). By completely inhibiting chlorophyll formation, some herbicides cause a characteristic very pale (almost white) yellowing of foliage. This may occur as a band across the centre of needles which were actively growing when the herbicide was applied (Fig.6). This is unlike any nutrient deficiency.

FIG.4 Effect of fungal attack on fascicles. Note that some needles in a fascicle can be affected more than others. (CS 39688)

FIG.5 Herbicide damage in radiata pine. Note irregular distribution. (CS 38412)

FIG.6 Herbicide damage in radiata pine. Note banding effect. (CS 38414)

Further Reading

FOREST RESEARCH INSTITUTE 1982: Aerial topdressing of forests. *New Zealand Forest Service, What's New in Forest Research No. 114.*

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WILL, G.M.; HODGKISS, P.D.; MADGWICK, H.A.I. 1983: Nutrient losses from litterbags containing *Pinus radiata* litter: influences of thinning, clearfelling, and urea fertiliser. *New Zealand Journal of Forestry Science 13:* 291-304 (New Zealand Forest Service Reprint 1692).

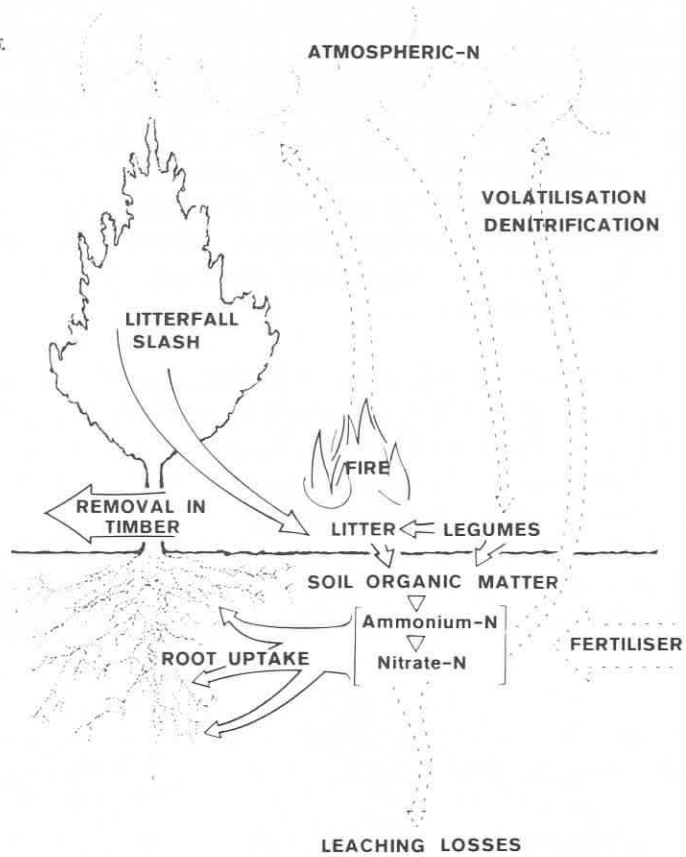
2. NITROGEN DEFICIENCY IN RADIATA PINE

Introduction

Nitrogen (N) deficiency in New Zealand plantations has been a particularly widespread problem in sand-dune forests. These sands are not soils in the normal sense of the term as they do not initially contain any organic matter, i.e., no topsoil is present. Organic matter is the key to nitrogen supply. Unlike phosphorus, potassium, and most other nutrients, little or no nitrogen is contained in or held on sand particles. Most nitrogen (95% or more) in surface soils is usually present in organic matter and is released as it decomposes.

Apart from small additions in rain, most nitrogen is naturally incorporated into a soil by nitrogen-fixing plants. This fixed nitrogen becomes part of soil humus through plant decomposition. As the decomposition proceeds further, the humus releases nitrogen in a form that plant roots can absorb. This uptake-decomposition sequence, known as the nitrogen cycle (Fig.1), is a continuous process. As soils develop, their nitrogen status is increased by nitrogen-fixing plants, but this can be counteracted by leaching losses, gaseous losses (return of nitrogen to the atmosphere by denitrification), and erosion or other processes which remove topsoil.

FIG.1 Nitrogen cycle in forests.



Nitrogen-deficient forests around the world occur on two main categories of soil.

(1) *Low organic matter soils.* Even though decomposition processes occur at normal rates, release of nitrogen is insufficient to sustain optimum tree growth because of the low total nitrogen capital of the soil.

(2) *Slow rates of decomposition soils.* Total quantities of organic matter (and nitrogen) are adequate but the microbial release (and cycling) of nitrogen in plant available (inorganic) form is slow and inadequate. This is typically the position with acid-peat soils and with forests in colder climates where litter builds up on the forest floor.

In New Zealand, Type 1 soils occur naturally in coastal sand-dune forests and are artificially induced in parts of most forests when logging operations remove topsoil from areas such as skid sites.

Type 2 soils are not as common in New Zealand as in some northern European countries. There are, however, some areas of peat, and related soils such as the gley-podzols, in Westland and Northland. In these situations, improved aeration through drainage is often the key to increasing the rate of decomposition and nitrogen release.

Another factor which can induce nitrogen stress in trees, particularly in the period immediately after planting, is competition by weeds (other vegetation). While the trees only have shallow and restricted root systems, vigorous plants such as grasses can compete very successfully for moisture and nutrients, and it is often the nitrogen supply to the trees which is most affected.

In the natural sequence of soil development, nitrogen-fixing plants such as legumes play a major role in improving nitrogen status. Artificial introduction and encouragement of these plants in forests where the soils are of low nitrogen status has proved very successful in sand forests. In fact, it would not be an exaggeration to say that the productivity of these forests is largely dependent on the presence of yellow perennial lupin (*Lupinus arboreus*). In the years of sand stabilisation before tree planting, the lupins are responsible for adding considerable amounts of nitrogen to the site. This continues until canopy closure when lupin growth is suppressed. Later in the rotation, whenever thinning occurs, lupin regrowth adds further nitrogen to the soil.

Other nitrogen-fixing plant species are being investigated for their potential to improve the nitrogen status of forest soils. Current silvicultural practice allows the growth of understorey species for most, if not all, of a rotation. On almost all sites, it could be of benefit if the understorey had a substantial nitrogen-fixing capacity.

A variety of nitrogen fertilisers are available – a much greater range than for other nutrients – but they can generally be placed in one of three types.

(i) Nitrate (NO_3) compounds such as sodium nitrate (nitrate of soda), which are quick-acting but can leach readily from the soil.

(ii) Ammonium (NH_4) compounds, which are also quick-acting but do not leach until converted in the soil into nitrates. Included in this group is urea, which is readily converted to ammonium compounds in most soils. Under some conditions, the nitrogen from these fertilisers can be lost by conversion to ammonia gas and volatilisation.

(iii) Slow-acting compounds, which are largely insoluble and not subject to loss by leaching or volatilisation. In most cases, microbial activity in the soil helps convert them to a soluble, 'available' form. This slow

solubility allows efficient plant uptake. Examples are magnesium ammonium phosphate (Magamp) and a range of urea-formaldehyde compounds (IBDU is one). These high-cost fertilisers are usually used only in special circumstances.

Deficiency Identification

Visual symptoms

The crowns of nitrogen-deficient trees are characteristically a uniform yellowish green, becoming yellow under severe conditions, and the needles are shorter than normal (Fig.2 and 3). Unlike the chlorosis caused by phosphorus, potassium, or magnesium deficiency, each needle is a uniform colour along its whole length and needles of all ages in all parts of the crown tend to be a similar light green, yellowish green, or yellow. There may be a tuft of greener foliage on the leader just below the terminal bud, particularly in young trees (Fig.4).

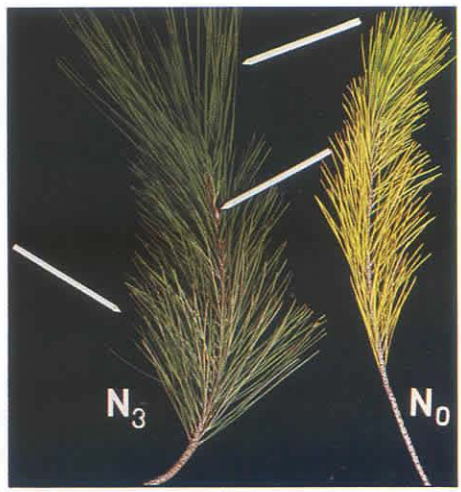


FIG.2 Nitrogen deficiency symptoms in radiata pine. On right (N_0), branch from nitrogen-deficient tree; note abnormally short needles with uniform greenish yellow colour. On left (N_3), branch from tree treated with nitrogen fertiliser the previous year; note increased length in foliage formed since fertiliser application and darker green colour of all foliage. (CS 18326)

FIG.3 Acutely nitrogen-deficient trees in sand-dune forest; note bare sand and absence of lupins. (CT 555)

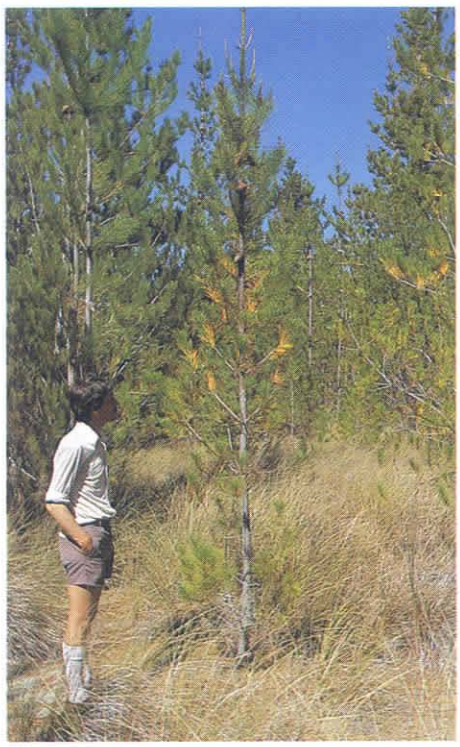


FIG.4 Young nitrogen-deficient tree. Note small branches and darker green foliage on top of leader; yellowish brown needles in mid crown are due to a needle-cast fungus.

Historically, plantations in Woodhill Forest and in forests in the Nelson district have been known for their good form and small branches. It is now recognised that the major, if not the sole cause of this fine branching and straight stems, is marginal nitrogen deficiency. Unless the deficiency is severe, it has much less effect on height growth than on diameter growth and branch growth. Nitrogen stress increases apical dominance and there is a notable absence of retarded leader symptoms, which often give rise to double or multiple leaders in trees on more fertile sites.

Other causes of similar symptoms

Chlorotic yellowish green foliage can be induced by a number of causes other than nitrogen deficiency in the soil. In fact, these other factors cause deficiency in the foliage by restricting either root uptake or bark transport of nitrogen. Thus, any agency that destroys roots or damages the bark may cause nitrogen-deficient foliage. Examples are root-destroying fungi or insects, and bark-chewing rodents or possums.

Foliage analyses

Less than 1.2% N in foliage indicates a degree of deficiency where economic response to fertilisers can be expected in most forests. In cases of severe deficiency, concentrations can be as low as 0.8% N. Between 1.2 and 1.5% N, tree growth is restricted by nitrogen deficiency but economic growth gains cannot be confidently predicted in all cases. Above 1.5% N in the foliage, growth is not restricted.

Occurrence of Nitrogen Deficiency in New Zealand

Figure 5 shows the major areas where nitrogen deficiency occurs but it must be remembered that any displacement of topsoil will induce nitrogen deficiency regardless of the soil type.

Coastal sands, dredge tailings, and other "raw materials" lacking humus are extremely nitrogen-deficient. On other soils, such as the pakihi soils in Westland, some eroded leached soils in Nelson, and podzolised sands in North Auckland, radiata pine plantations respond well to nitrogen fertiliser. Good responses are also occurring in second-rotation plantations on clay soils in the North Auckland region. There are other soils and regions, such as the pumice plateau, where many stands are marginal for nitrogen. Here, fertiliser response is not usually economic though much greater and more profitable responses result where fertiliser application is timed to follow thinning. It appears that, after thinning, nitrogen becomes the major factor limiting crown expansion of the remaining trees. Consequently, an application of nitrogen fertiliser at this stage markedly increases canopy expansion.

Correction of Nitrogen Deficiency

Legumes

Legumes can fix substantial quantities of nitrogen efficiently and economically on deficient sites. Just as in New Zealand pastures where grasses are supplied with nitrogen by clovers, so legumes can be used to supply nitrogen to forests. At the present time lupins are routinely sown ahead of planting in sand-dune forests (Fig.6) to provide a biological rather than a bag source of nitrogen for the trees.

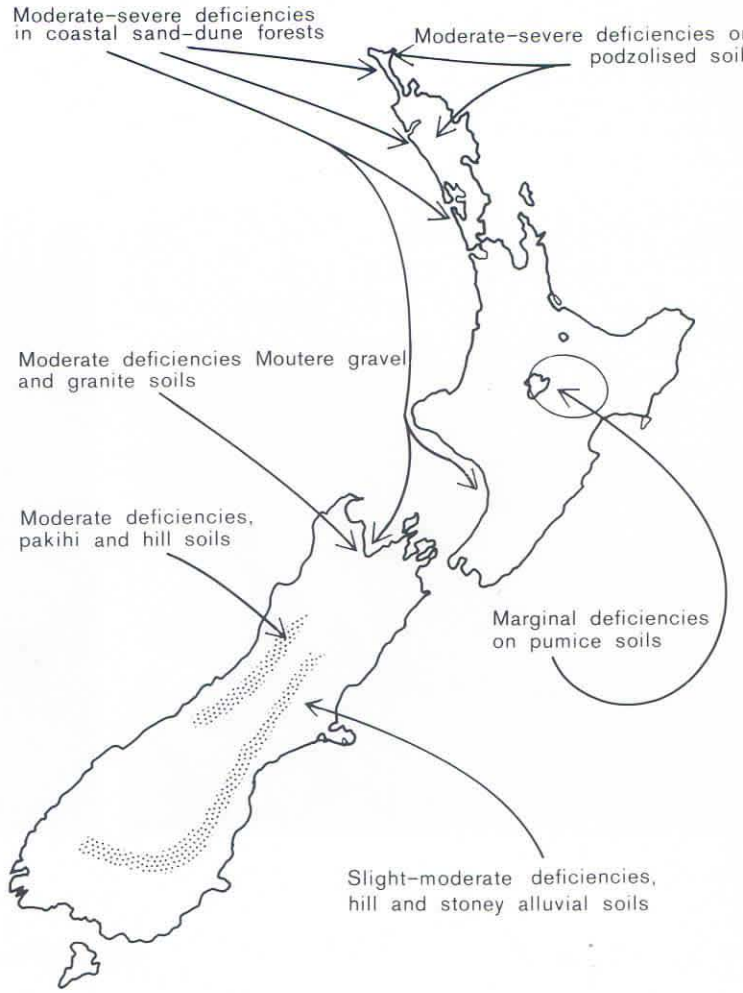

Moderate-severe deficiencies in coastal sand-dune forests
Moderate-severe deficiencies on podzolised soils
Moderate deficiencies Moutere gravel and granite soils
Moderate deficiencies, pakihi and hill soils
Marginal deficiencies on pumice soils
Slight-moderate deficiencies, hill and stoney alluvial soils

FIG.5 Major areas of nitrogen deficiency in New Zealand forests.

FIG.6 Lupins in sand-dune forest. Note dark green foliage on right-hand tree growing beside lupin; by comparison, the nitrogen-deficient tree on left is not near a lupin bush and has yellowish foliage. (CS 9401)

Fertilisers

Fertilisers should be used on soil types where suitable legumes have not been proven as yet or where rapid, short-term boosts to nitrogen supply are required.

Where nitrogen alone is required, urea is the preferred fertiliser because of its lower cost per unit of nitrogen. Where both nitrogen and phosphorus are needed, diammonium phosphate (DAP) should be used. Fertiliser nitrogen should be applied in the spring at the rate of about 200 kg N/ha (i.e., 450 kg urea/ha). Responses can be obtained at other times of the year but maximum results can be expected in the spring when tree demands are high and losses through volatilisation and leaching are likely to be low.

3. PHOSPHORUS DEFICIENCY IN RADIATA PINE

Introduction

In Europe, more than 300 years ago, it was found that tree growth was markedly increased when phosphorus (P) containing materials, such as wood-ash and basic-slag, were applied to some forest stands. Today, phosphate fertilisers play a significant part in maintaining and increasing forest productivity in many countries. This is particularly so where plantations have been established on previously non-forest land, such as unproductive agricultural land and peat.

Most New Zealand soils (and their parent materials) are inherently low in phosphorus. As a result, our agricultural productivity is dependent on phosphate fertilisers to a much greater degree than those of European and North American countries. Phosphate fertilisers became recognised as an essential part of New Zealand agricultural management from early this century, but their use in forestry only dates from about 1950. The previously accepted views were that pines could (or should) grow on even the least fertile of soils and that the use of fertilisers was not warranted or justified.

Experience in Riverhead Forest began a re-evaluation, followed by a marked change in attitude. Planting began in the 1920s, and stands initially seemed healthy and productive. However, increasing ill-thrift, dieback, and in extreme cases mortality gradually forced a reassessment of the forest's potential. Forest management had been scaled down to a caretaker-only basis in the early 1950s. Then, stimulated by Australian experience, fertiliser trials were begun in 1952. It was soon evident that applications of phosphate fertiliser were able to rejuvenate tree crowns and dramatically increase growth rates (*see* Fig.1 in Section 1). Today, it is accepted that phosphate fertilisers are an essential part of forest management in several parts of New Zealand – particularly those on the low phosphorus soils in the Auckland, Northland, Coromandel, Nelson, and Westland areas.

Deficiency Identification

Visual symptoms

The overall effect of phosphorus deficiency in adult trees is to give narrow, "thin" crowns. This is caused by the following individual features: (1) narrow spire-like crowns result from normal height growth but restricted diameter and branch growth (Fig.1); (2) needles are abnormally short in length; and (3) needle shed is accelerated and only one or two seasons' needles are retained (Fig.2).

In severely deficient trees, foliage colour is a dull to greyish green, and this is accompanied by leader dieback in extreme cases. The combination of foliage colour and dead tops used to give many phosphorus-deficient stands a characteristic grey appearance (Fig.3).

Since the introduction of fertiliser applications, phosphorus deficiency symptoms are usually only seen in young trees. Here, the most characteristic feature is short yellow-tipped needles on the ends of branches, giving a flat end to shoots when seen in profile (Fig.4).

FIG.1 Narrow crowns characteristic of phosphorus deficiency.

FIG.2 Phosphorus-deficient radiata pine. Note short needles on centre tree and retention of only 1 year's needles.

FIG.3 Grey foliage and dead tops in a stand showing extreme phosphorus deficiency, with possible additional calcium deficiency. (CS 17551)

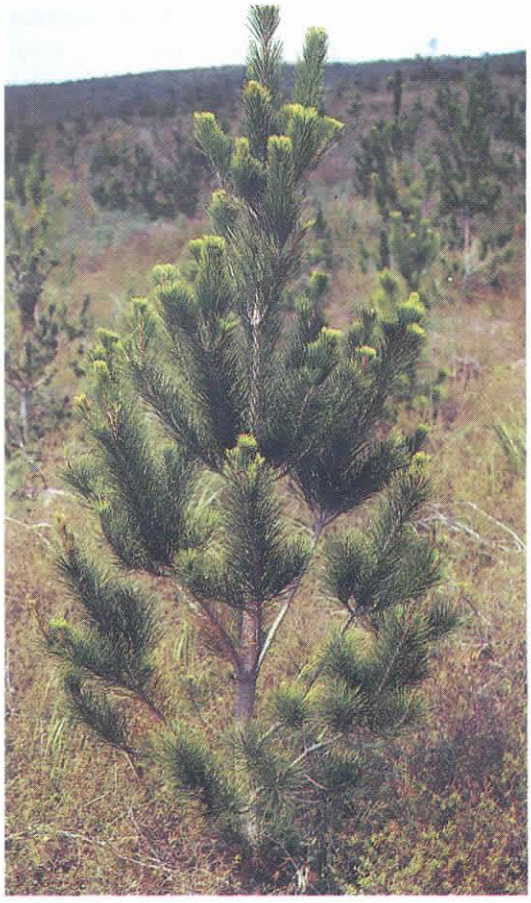


FIG.4 Needle-tip chlorosis in young trees. (CT 1144)

Although not specific to phosphorus deficiency (*see* boron and copper), needle fusion is commonly observed in moderately phosphorus-deficient stands. Individual needles in a fascicle fail to separate and in severe cases the fused fascicles are stunted and distorted (Fig.5 and 6).

FIG.5 Needle fusion in radiata pine. Left-hand shoot severely affected. (CS 9423)

FIG.6 Needle fusion in radiata pine. Tree on left affected but not tree on right. (CN 14107)

Other causes of similar symptoms

Nitrogen deficiency also restricts diameter and branch growth resulting in narrow crowns, fine branching, and abnormally short needles. However, needle colour is very different. Phosphorus-deficient trees do not have the uniformly yellowish green foliage characteristic of nitrogen deficiency.

The development of fused needles seems to have a genetic base. Even on fertile sites, one tree in several thousand may develop fused needles for no known reason. Not all trees on a phosphorus-deficient site will develop fused needles (Fig.6), but is is not uncommon for 10–20% of trees to be affected.

As needle fusion has been observed in boron- and copper-deficient trees as well as those deficient in phosphorus, fused needle symptoms are thought to result from a nutrient imbalance or a range of nutrient disorders rather than a specific phosphorus deficiency.

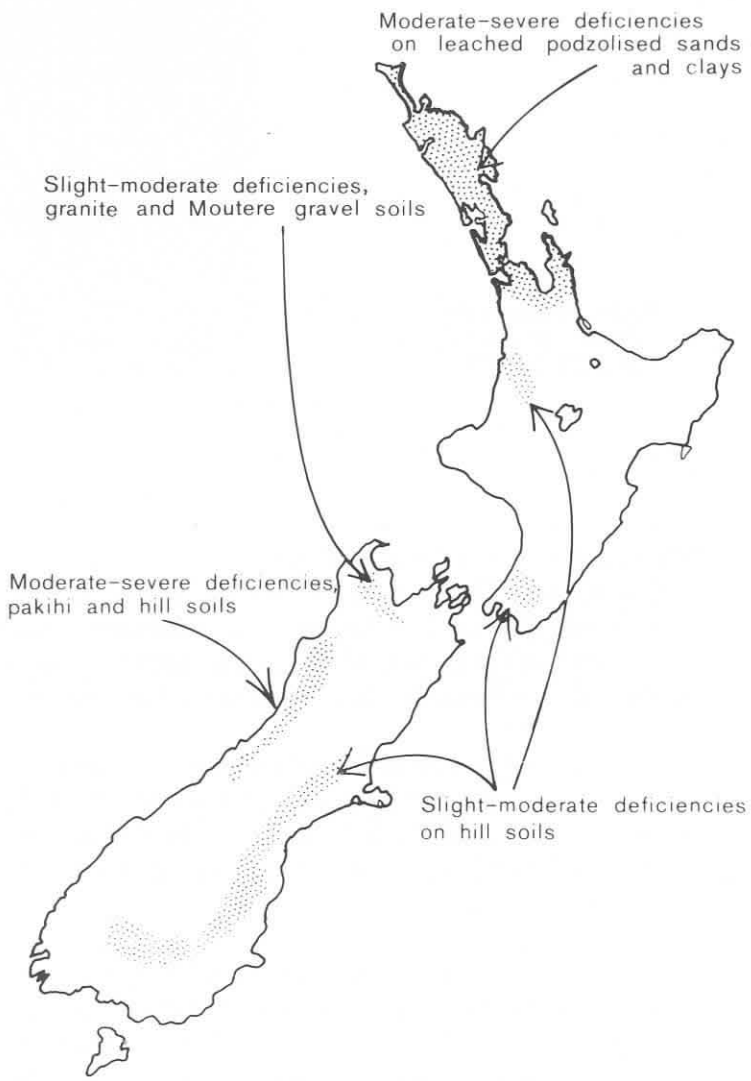
Foliage analyses

Growth is affected below 0.14% P; economic responses to fertiliser are obtained below 0.11%; and visual deficiency symptoms are present below 0.10%.

Occurrence of Phosphorus Deficiency in New Zealand

In New Zealand agriculture, superphosphate is a universal fertiliser required on most soil types. Although phosphorus deficiency is not as widespread in forests, it does occur on a range of soils throughout the country (Fig.7). Forests on the podzolised sands and clay soils of North Auckland, Northland, and the Coromandel Peninsula were extremely deficient before the introduction of a regular fertiliser programme. The pakihi soils in Westland and the more weathered, leached soils on granite and Moutere gravels in Nelson are also very low in phosphorus. In other parts of the country, there are hill soils which show various degrees of phosphorus deficiency – these range from the Maramarua-King Country areas, to the Rimutaka area near Wellington, and to isolated areas in the eastern and southern parts of the South Island.

FIG.7 Major areas of phosphorus deficiency in New Zealand forests.


Moderate–severe deficiencies on leached podzolised sands and clays
Slight–moderate deficiencies, granite and Moutere gravel soils
Moderate–severe deficiencies, pakihi and hill soils
Slight–moderate deficiencies on hill soils

Correction of Phosphorus Deficiency by Fertilisers

Types of fertiliser

As in agriculture, superphosphate (10% P) has been the most widely used fertiliser. Until recent years, it was the only fertiliser used. DAP (18-20-0) is now in routine use on sites that respond to nitrogen as well as phosphate. Triple super became available in New Zealand in 1983 and has been used in many operations (*see* Section 1, Table 2). It has the advantages of: (1) high analysis (20% P), reducing the amount of fertiliser that has to be transported and applied; and (2) it is a well-granulated material.

There are encouraging indications that rock phosphates will be effective fertilisers in the future for a number of situations.

Rates

At time of planting – in a spade slit beside the tree, apply approximately 18 g P (i.e., 180 g super or 85 g DAP).

Aerially applied – in the days of poor distribution, rates were up to 1200 kg super/ha; currently 900 kg/ha are used, and with optimum spreading, this should fall to 600–800 kg/ha. Triple super and DAP are applied at 450 kg/ha (i.e., approximately the same rate of phosphorus). Fertiliser is applied when foliage phosphorus levels fall below 0.11%. In practice, this is at intervals of up to 10 years. More frequent but lower rates may be beneficial and economically advantageous in some situations.

4. POTASSIUM AND CALCIUM DEFICIENCIES IN RADIATA PINE

Introduction

In the early 1960s, a trial planting of pines on one isolated area of pakihi soil in the Grey Valley, Westland, showed symptoms of potassium (K) deficiency. Later, areas of potassium-deficient plantations were recognised in the Nelson district on ultra-basic "mineral belt" soils. It was not so much an absolute deficiency in these soils but the presence of overwhelming quantities of magnesium which made adequate uptake of potassium difficult. Within the trees, high magnesium/potassium ratios accentuated the potassium deficiency. Applications of potash fertiliser have only brought about temporary improvements.

These restricted areas of potassium deficiency in the South Island have not warranted any management-scale use of fertilisers. However, since the late 1970s other areas of potassium deficiency have been recognised in new plantings in Northland. On some of the deeply weathered, podzolised, strongly leached soils in the Kaikohe-Kaitaia districts, considerable areas of potassium-deficient plantations have been found – a few of them severely deficient. Management-scale use of potash fertilisers is becoming routine in these areas.

Calcium (Ca) deficiency, induced in glasshouse studies, causes resin exudation around buds and on stems; it ultimately results in shoot death. These symptoms are very similar to those seen in adult trees in some of our severely phosphorus-deficient forests (e.g., Riverhead and Tairua). In these forests, foliage calcium levels are low and probably deficient, but the specific individual roles of calcium and phosphorus have not been studied (Fig. 1). This is because all phosphate fertilisers used in early trials and management operations contained both phosphorus and calcium.

Potassium Deficiency Identification

Visual symptoms

Needle-tip chlorosis uniformly affects all needles in a fascicle and all fascicles of the same age. Not as golden as magnesium deficiency and occurs in the lower part of the crown (Fig. 2 and 3). Intensifies in late winter, and this is probably associated with the expansion of pollen cones, which have a high potassium content.

Other causes of similar symptoms

Potassium deficiency can be confused with magnesium deficiency, and both deficiencies must be distinguished from chlorosis caused by needle-cast fungi. Needle-cast fungi rarely attack tree crowns and individual needles in the uniform pattern characteristic of nutrient deficiencies. Foliage analysis can quickly and easily identify magnesium and potassium deficiencies.

Foliage analyses

More than 0.5% K in foliage indicates an adequate supply of potassium. Less than 0.3% K is associated with marked chlorosis and reduced growth.

FIG.1 Dieback in radiata pine. This stand is phosphorus-deficient but calcium deficiency has probably contributed to the extreme dieback.

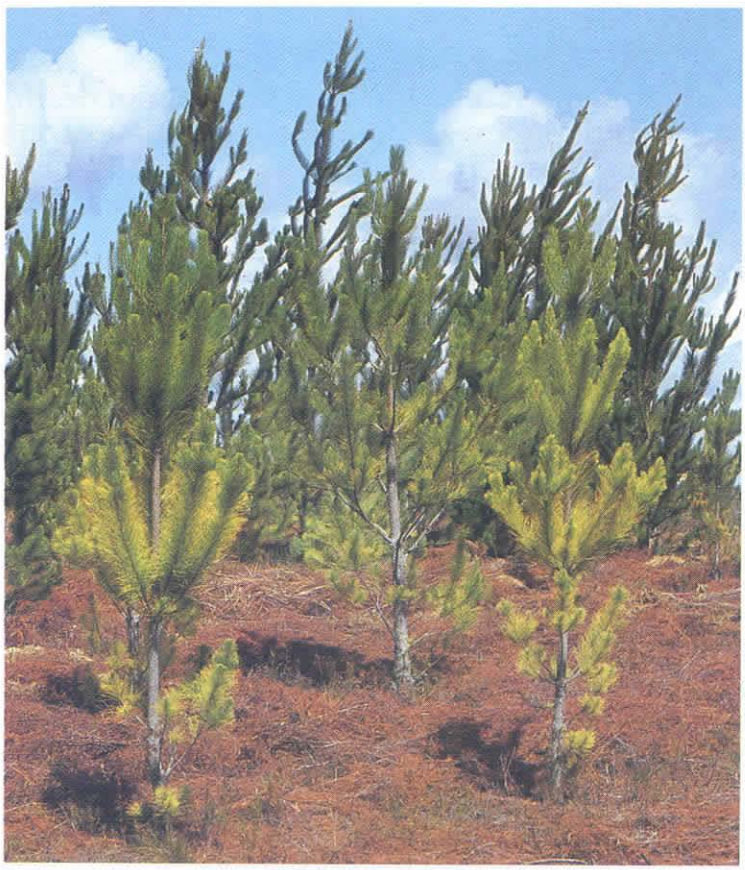
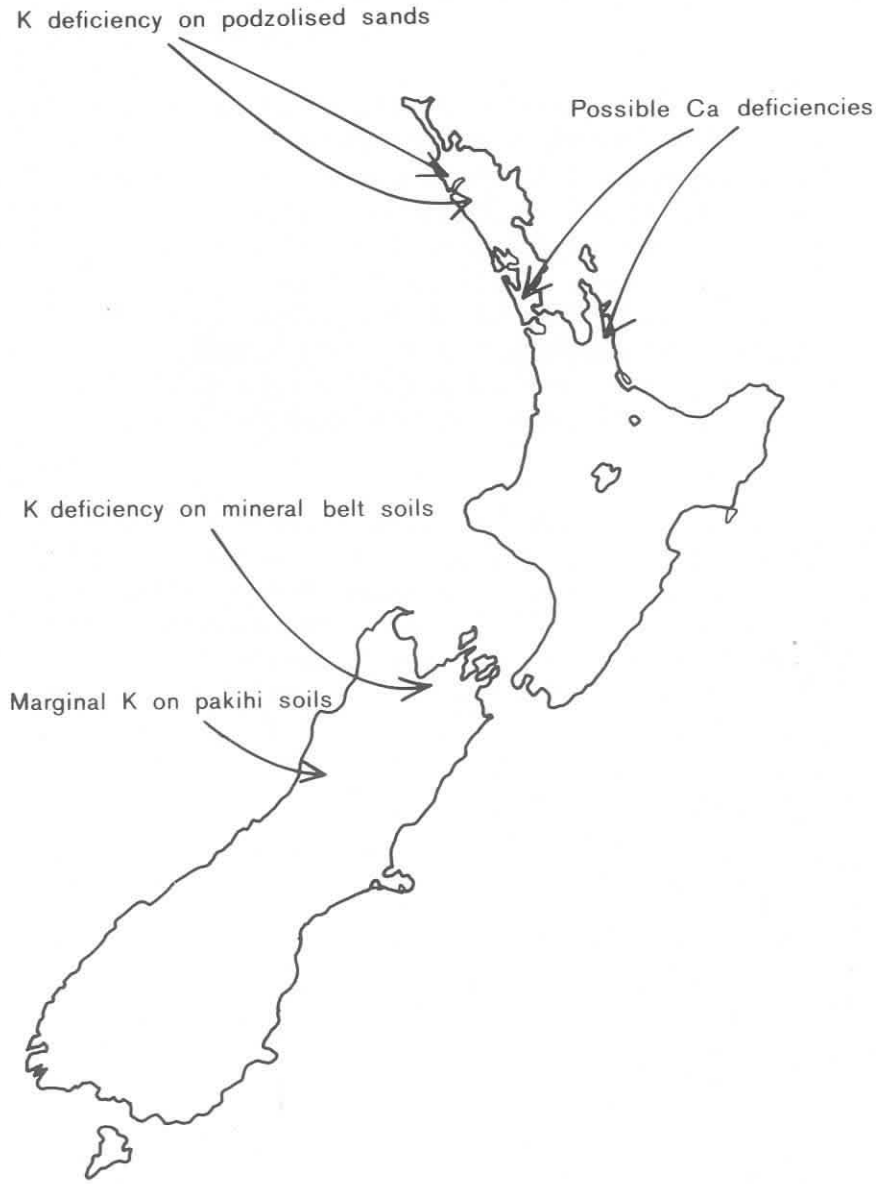


FIG.2 & 3 Potassium deficiency in radiata pine. (CS 27530)

Occurrence of Potassium Deficiency in New Zealand

Potassium deficiency occurs in small areas of mineral belt and pakihi soils in the South Island, and in significant, but as yet not fully surveyed, areas of podzolised, leached, sandy soils in Northland (Fig.4).

FIG.4 Major areas of potassium and calcium deficiencies in New Zealand forests.


K deficiency on podzolised sands
Possible Ca deficiencies
K deficiency on mineral belt soils
Marginal K on pakihi soils

Correction of Potassium Deficiency by Fertilisers

Excellent growth and complete prevention of visual symptoms have resulted from the application of 100 kg K/ha (as potassium chloride at 200 kg/ha). In many situations lower applications will certainly be adequate. The length of time an application will last is as yet poorly defined. In practice, potash fertiliser is likely to be applied along with other nutrients, e.g., as potassic super or an N:P:K high-analysis fertiliser. One site in Northland, which developed extreme potassium deficiency when nitrogen and phosphate were applied, is also known to be copper, and probably zinc, deficient. This emphasises the need to apply a "balanced" fertiliser to sites which are low in a number of nutrients.

5. MAGNESIUM DEFICIENCY IN RADIATA PINE

Introduction

The Taupo ash shower, which is the parent material from which many of the soils in the central region of the North Island have been formed, is naturally low in magnesium (Mg). Extreme magnesium deficiency was found in radiata pine seedlings in a newly developed part of Kaingaroa Nursery in the late 1950s. Magnesium deficiency undoubtedly occurred in the extensive pine plantations of the central North Island in first rotation crops but it was not reported and identified as such until the early 1960s.

A golden yellow needle-tip chlorosis was observed in spring in northern Kaingaroa Forest in young trees, particularly those that had been pruned within the previous 6–9 months. The spring of 1963 was one of the driest on record and needle-tip chlorosis was more widespread and intense than normal. Investigations established the following points:

(i) The chlorosis caused by magnesium deficiency becomes most obvious during the spring when magnesium is withdrawn from older foliage to satisfy the trees' requirements for the flush of new foliage produced at that time.

(ii) When pruning has reduced the amount of existing foliage, the demand on the remaining foliage is greater and the chlorosis becomes more intense.

(iii) During periods of drought, uptake from the nutrient-rich topsoil is reduced, placing an even greater demand on existing foliage.

(iv) On pumice soils, symptoms are most marked in young trees whose root systems are confined to the surface layers of soil. Many deeper buried volcanic ashes have higher magnesium contents and, when tree roots reach those depths, deficiency symptoms are rarely seen.

Deficiency Identification

Visual symptoms

A golden yellow needle-tip chlorosis that affects all needles within a fascicle and all fascicles within a flush of growth to a similar extent. It initially occurs in the upper crown (this may be the whole crown of recently pruned trees) and affects the previous season's foliage – particularly during the period of rapid foliage expansion in the spring (Fig.1 and 2).

When a severe deficiency causes the chlorosis to extend to a third or more of the needle length, needle tips often die and turn brown (Fig.2).

Mild magnesium deficiency does not usually produce any noticeable difference in tree crown shape or growth rate. However, in cases of acute deficiency, growth is stunted and the needle-tip chlorosis is present on current season's foliage (Fig.3).

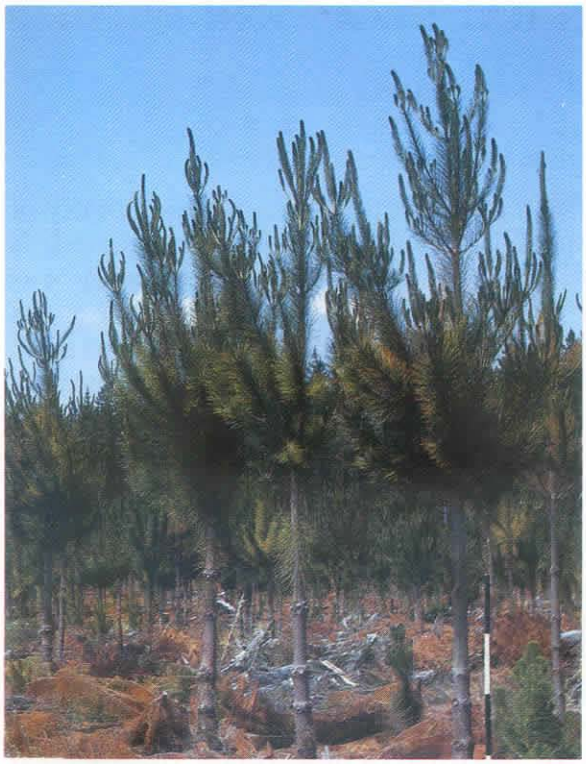


FIG.1 Magnesium deficiency in a recently pruned stand of radiata pine. Photograph taken in the spring of a dry year. (CS 3811)

FIG.2 Severe magnesium deficiency in farm forestry plantation in spring. Some needle tips are dying. (CT 2312)

FIG.3 Needle-tip chlorosis on current season's needles in a tree with extreme magnesium deficiency. (CS 23446)

Other causes of similar symptoms

Potassium deficiency causes a similar needle-tip chlorosis, but the chlorosis generally tends to be a paler, less golden colour. In addition, potassium deficiency is especially prevalent in the lower part of the crown, and intensifies in late winter rather than spring.

Several needle-cast fungi cause foliage yellowing but, unlike nutrient deficiencies, adjacent fascicles and needles within a fascicle are often affected to different degrees (Fig.4; *see also* Fig.4 in Section 1). Also, the chlorosis does not always begin at the needle tip and extend progressively down. Another characteristic is the needle-cast itself: nutrient deficiencies do not lead to a sudden loss of foliage.

Foliage analyses

Concentrations of between 0.10% and 0.07% Mg in the foliage indicate a marginal status. Within this range an increasing proportion of trees will show chlorosis but growth is probably not appreciably affected. Below

0.07% Mg, most trees in a stand will show chlorosis and growth may be decreased. Severely stunted trees showing chlorosis in current foliage have levels of about 0.04% Mg.

Occurrence of Magnesium Deficiency in New Zealand

The more extreme phases of magnesium deficiency, where growth is stunted and current season's foliage is chlorotic, have only been observed on some coarse pumice soils in the southern part of Kaingaroa Forest and Waimihia Forest. Less severe symptoms in dry years and/or after pruning are common throughout forests on the pumice soils in the central North Island region. Slight symptoms are also fairly common in parts of the Nelson and Westland regions in the South Island (Fig.5).

FIG.4 Needle chlorosis caused by needle-cast fungal attack. Note several features not typical of a nutrient deficiency: different degrees of chlorosis in foliage of the same age on the same branch; different degrees and stages of attack on branches of the same age; and extensive loss of foliage on some branches. (CT 2304)

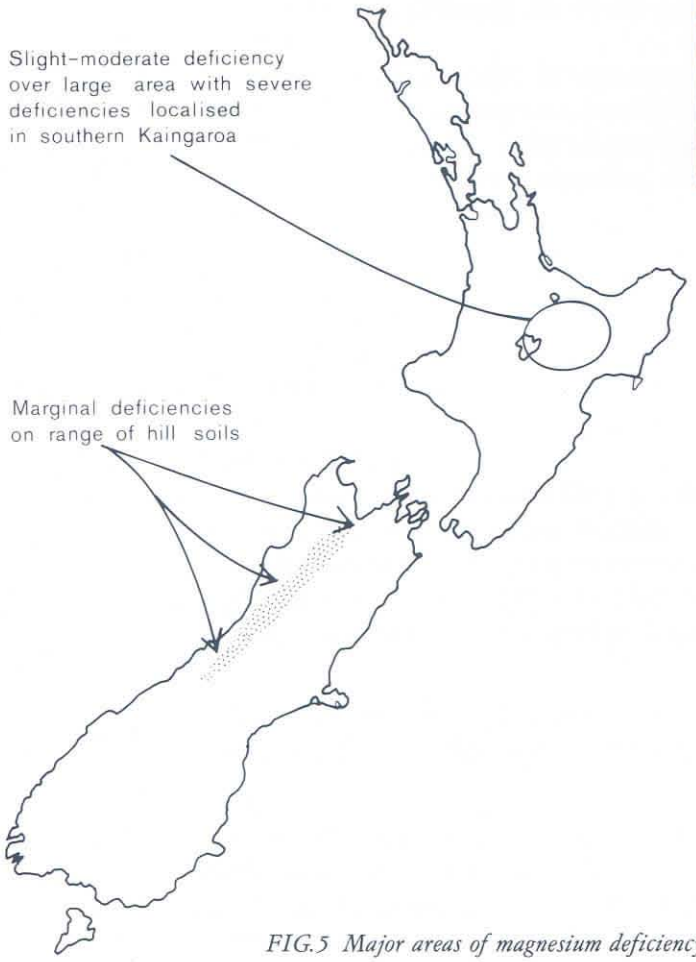

Slight–moderate deficiency over large area with severe deficiencies localised in southern Kaingaroa
Marginal deficiencies on range of hill soils

FIG.5 Major areas of magnesium deficiency in New Zealand forests.

Correction of Magnesium Deficiency by Fertilisers

Magnesium fertilisers have only recently been applied to forests on a routine management basis. It is believed that the growth of younger stands, seasonally showing slight chlorosis, is not appreciably decreased, and the trees outgrow the condition with age. In severely affected areas, applications of dolomite and other magnesium fertilisers have brought about marked improvements in foliage colour and tree growth rates. As this has taken several years and the trees still show some symptoms, the rate of dolomite applied (1 tonne/ha) may not be the optimum.

6. BORON DEFICIENCY IN RADIATA PINE

Introduction

Boron (B) deficiency affecting the growth of forest trees was first identified and described in plantations of pines, eucalypts, and some other species in Kenya and Northern Rhodesia in the late 1950s. Characteristic symptoms were death of shoots and buds. Boron deficiency has since been shown to be the cause of extensive dieback in radiata pine plantations in Australia, Chile, and New Zealand.

Boron deficiency was first recognised and described in New Zealand in 1962. It was found to be the cause of severe dieback and malformation, occurring in plantations on the deeply weathered, strongly leached granite and Moutere gravel soils to the west of Nelson (Fig.1). The deficiency has since been recognised as the cause of dieback in a number of forests in the Nelson and Canterbury Conservancies. It also occurs on certain soils in other parts of the South Island and in the central region of the North Island. Before boron deficiency was identified, the dieback symptoms were attributed to other causes, such as drought, frost, or fungal attack. In the days of less-intensive silvicultural management, they may not even have been observed.

Boron deficiency is not uncommon in horticultural and agricultural crops in New Zealand, and borated superphosphate is in standard use. It is particularly used when growing susceptible crops, such as brassicas and lucerne. Recent experience has shown that radiata pine is more prone to boron deficiency than most plant species. In areas where native vegetation and pasture species exhibit no obvious symptoms, radiata pine can suffer severe dieback. Although less susceptible than radiata pine, gorse and broom show dieback caused by boron deficiency.

Of all plant mineral nutrients, boron has the narrowest range between deficiency and toxicity. Unlike most other nutrients (e.g., phosphorus and calcium) where fertiliser overdoses cause little or no harm, boron fertiliser applications must be carefully regulated to avoid toxicity. Tolerance to overdoses is small. What is an effective fertiliser rate for plantations on one type of soil (e.g., a clay) may well lead to toxicity on another (e.g., gravel or sand).

Boron is a relatively immobile nutrient within plants. Unlike many other nutrients (e.g., nitrogen and magnesium), it is not redistributed to growing points by internal cycling. Current uptake by the roots appears to determine the concentrations that are incorporated into shoots and foliage as they are formed.

The onset and severity of deficiency symptoms (dieback) are closely associated with moisture stress. Characteristically, symptoms first develop in midsummer and are most severe in drought years. The severe droughts that occurred in eastern Australia and some parts of New Zealand in 1982-83 resulted in unusually widespread boron deficiency in stands of radiata pine.

Deficiency Identification

Visual symptoms

Deficiencies of other nutrients, such as phosphorus, nitrogen, and potassium, are evident throughout the year, but the visible effects of

boron deficiency are distinctly seasonal in occurrence. Spring growth from unaffected buds appears normal, and it is not until midsummer or later that leading shoots show clearly recognisable symptoms.

Boron deficiency causes the death of buds and shoots. Usually, the shoot of the main leader is affected first, followed by the shoots on the ends of the upper branches. Subordinate laterals are also affected in severe cases. Where a tree has been affected by boron deficiency for several years, a leader and main branches are not clearly recognisable (Fig. 2). They are replaced by a considerable number of shoots of similar vigour.

The nature of dieback symptoms can be highly variable, depending on the vigour of the tree, previous history of boron deficiency, and the time of onset (Fig.3 and 4). For convenience, however, the range in symptoms can be grouped into two classes – "shoot dieback" and "tip dieback".

FIG.1 Dead tops and malformation resulting from boron deficiency. (CS 2806)

FIG.2 Eight-year-old radiata pine severely affected by repeated dieback caused by boron deficiency. Photograph taken in early summer before current season's dieback became evident.

FIG.3 Shoot and tip dieback affecting almost all current season's growth. Note regrowth from fascicle buds. (CS 36247)

FIG.4 Rather unusual case of extensive dieback late in season (winter). Note even spread of symptoms over whole tree. Dieback occurred first on leader and spread gradually to lower branches, which were less severely affected. (CN 14911)

Shoot dieback

Leading shoots are typically affected during the period of rapid elongation. When observed later, the basal portion appears normal but the apical portion has died more or less abruptly before the uppermost needle fascicles have extended beyond 1–3 cm. The unopened fascicles are usually shed, and rapid drying often causes the unlignified stem to crook or curl into an inverted U- or J-shape (Fig.5).

There is usually a transitional zone between the unaffected and dead sectors of larger shoots but this is highly variable in length. White dots and patches of dried resin commonly occur on the dead and transitional portions of the stem (Fig.6).

The pith is completely brown within the dead portion of the stem and a little distance below. Longitudinal sections through the transitional zone usually show some evidence of pith breakdown and discoloration, and the zone may be marked by conspicuous dark brown spots. Although these dark brown spots are not always present, it appears that they are direct evidence of boron deficiency (Fig.6).

Shoot death is followed by the rapid production of secondary shoots from needle fascicles in the lower portion of the transitional zone or immediately below it (Fig.3). This shoot regrowth often completely conceals previous dieback by late spring of the following year (Fig.2).

Tip dieback

There is no sharp separation between shoot dieback and tip dieback, and the two forms may occur on the same tree. Tip dieback seems to result from later, more gradual, or less acute deficiency. The U- or J-shaped distortion is absent and bud death alone may occur. In most cases, however, a dead bud is surrounded by some dead or discoloured needles. Terminal needles, whether discoloured or not, are often short and closely spaced because of incomplete shoot extension (Fig.7). Dead buds are usually infiltrated by and/or coated with resin (Fig.7).

FIG.5 Shoot dieback caused by boron deficiency. Note curling of dead stems in inverted 'J'. (CS 5154)

FIG.6 Shoot dieback. Note (1) completely dead upper shoots and (2) intermediate zone with short yellow-tipped needles, brown spots in pith, and resin on stem. (CS 2513)

FIG.7 Tip dieback. Note dead buds, resin coating, yellow needles, and fascicle shoots (CS 36248)

One or more lateral buds often survive on live apices, and the subsequent development of shoots from these may obscure the loss of the terminal bud. Where no surviving lateral buds are present, fascicle buds usually develop within a short time (Fig.7).

Effects on form and growth

In stands affected by limited and infrequent tip dieback, most trees escape stem malformation. The consequences of shoot dieback are more pronounced and permanent; trees usually exhibit reduced height growth and numerous distortions of the main stem (Fig.1). Severe chronic deficiency, in which most leading shoots are damaged almost every year, results in stunted dense trees resembling artificial hedges (Fig.2 and 3).

The appearance of tip dieback in young trees before canopy closure is an almost certain forerunner of severe shoot dieback and malformation in later years – particularly dry ones.

Any visual symptoms of boron deficiency in young trees should be the trigger for preventative fertiliser applications.

Other causes of similar symptoms

Fungal attacks can result in symptoms similar to shoot dieback. If shoots are examined some time after death has occurred, it is usually impossible to distinguish between boron deficiency and fungal attack. At an earlier stage, it may be possible to identify a fungal attack if it has originated some distance back from the leading bud. Fungal entry through a stem split or a single needle fascicle can be fairly easily distinguished from boron deficiency whose symptoms always originate and are severest in the apex of the bud. While fungal attack can occur in almost any month of the year, boron deficiency only develops from midsummer to midwinter.

Where there is doubt, a foliage sample should be analysed to determine whether there is a boron deficiency. When foliage levels of boron are low, any dieback is almost certainly due to deficiency. When foliage levels are high, any dieback is certain to be caused by fungal attack. At intermediate (marginal) foliage levels of boron, there may well be cases where fungal attack causes dieback on trees which in midsummer of some years also exhibit boron deficiency symptoms.

Foliage analyses

Soon after boron deficiency was identified and described, 8 ppm B in the foliage was suggested as the critical level below which dieback occurred. Further experience has shown that, while this value is still true in many districts, plantations in Southland can have levels as low as 6 ppm and show no dieback. On the other hand, it has been reported that in northern New South Wales dieback occurs at foliage levels below about 12 to 14 ppm. This suggests that, in addition to boron availability in the soil, the climatic factors of temperature and moisture availability are also involved in the development of dieback.

Occurrence of Boron Deficiency in New Zealand

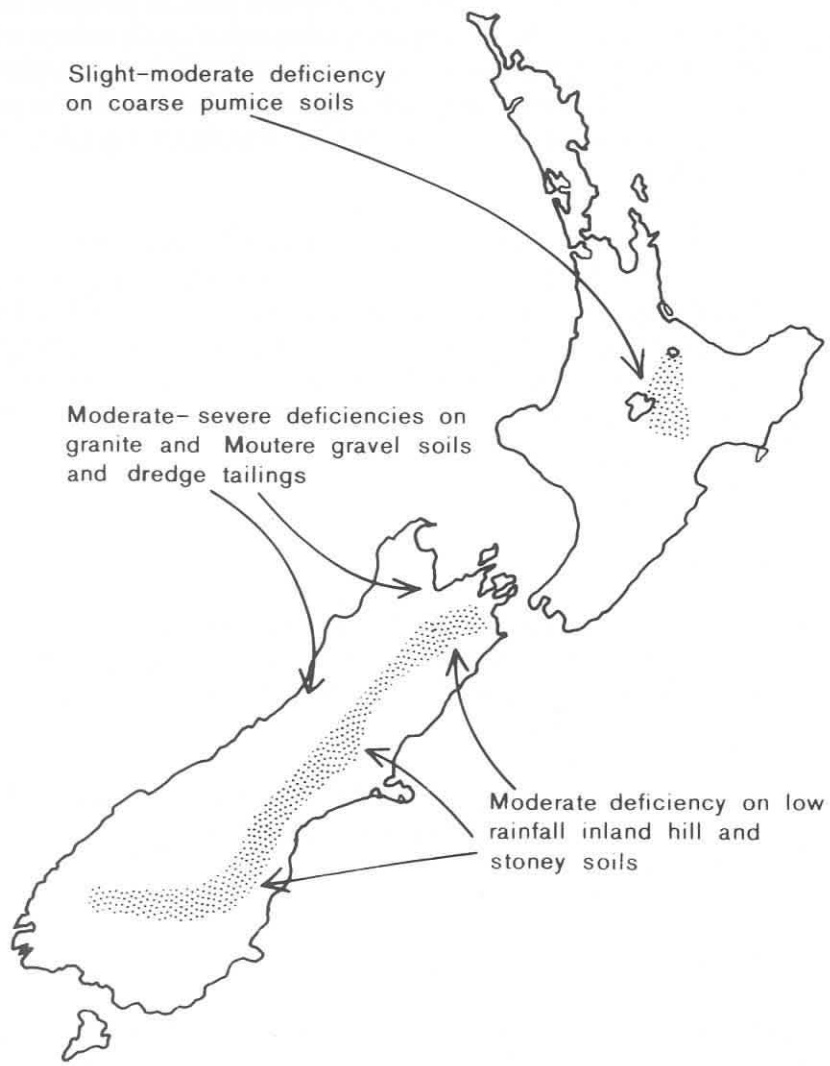
In the South Island ' on deficiency has been observed and corrected on several soil types r a range of climatic conditions (Fig.8). In the

North Island, low levels of foliage boron occur on some coarse pumice soils and dieback symptoms have been recorded, particularly in dry years. The only area to have received fertiliser is a plantation on the southern slopes of Mount Tarawera.

Research by the DSIR Soil Bureau has shown high total boron levels in many South Island soils on which trees develop deficiency. Conversely, forests on soils low in total boron in the Coromandel and North Auckland areas have not been affected by deficiency. It appears that the availability of boron to trees is not closely related to the total soil concentration of boron, but is governed by other factors, such as rainfall, soil depth, and moisture storage capacity.

In an experiment in Kaingaroa Forest, slash removal and repeated litter rakings have been associated with considerably lower levels of boron in the foliage of second-rotation trees. The reduction is greater than for any other nutrient. This suggests that, particularly in areas where the boron status is only just adequate, second and subsequent rotations will need careful monitoring to determine the need for boron fertiliser.

FIG.8 Major areas of boron deficiency in New Zealand forests.


Slight–moderate deficiency on coarse pumice soils
Moderate– severe deficiencies on granite and Moutere gravel soils and dredge tailings
Moderate deficiency on low rainfall inland hill and stoney soils

Correction of Boron Deficiency by Fertilisers

Fertilisers are the only practical method of improving the boron status of forest plantations. Although it is probable that reduction of moisture stress by irrigation would improve boron uptake, this cannot be envisaged on a management scale. Because of the ever-present danger of toxicity caused by excess, fertiliser applications must be made with great care. The same chemicals that are used in boron fertilisers are often used as weed killers. This is well illustrated by the 100% mortality that occurred some years ago in a new planting that, by mistake, was treated with 60 g of *fertiliser borate* per tree instead of the recommended 60 g of *borated superphosphate.* The boron concentration of fertiliser borate is 20 times that of borated superphosphate.

Where other fertilisers are being applied to individual trees at time of planting, appropriate amounts of boron can be included in the fertiliser mix. However, as with other nutrients, fertiliser applied in this way only provides an adequate nutrient source for a few years.

Broadcasting is the most effective method of application, and in nearly all situations the only practical means is to use aircraft. Because even the mildest boron deficiency kills the leading bud, causing loss of height growth and malformation, fertiliser application should be to prevent rather than to cure.

In severely deficient areas, fertilisers will be needed within 2 or 3 years of planting (in extreme situations, dieback can develop within 12 months of planting). Where boron deficiency is only slight or moderate, its appearance will be delayed until nearer canopy closure. This is the period in the life of a tree crop when there is greatest nutrient uptake, placing maximum demand on soil reserves.

Fertiliser application should precede the onset of dieback. Foliage analyses and local experience should be used in scheduling fertiliser applications. In new forests where experience is limited, particular note should be taken of trees in stress situations. For example, shallow soils on ridges will have lower total nutrients and be more droughty. Dieback on such sites may give a year or two warning of more general dieback in the plantation.

Application Rates

Trials and management operations have shown that effective deficiency prevention and correction can be achieved by applying 4 to 8 kg B/ha. On lighter sandy and gravelly soils the lower rate should be used as toxicity can occur at 8 kg B/ha.

Where boron is the only fertiliser being applied, total amounts of fertiliser are low: 4 kg B/ha is equal to 28 kg of a fertiliser containing 14% B 44% B_2O_3).

Types of Fertiliser

When standard agricultural-type sodium borate fertilisers have been used, dieback has stopped within a few months and increased foliage boron

concentrations have continued for about 4 years. A longer-lasting effect can be expected in stands where an established litter layer and/or thinning slash will promote nutrient cycling.

Successful applications have also been made with the less-soluble calcium borate, colemanite. Alone or in mixture with a soluble sodium borate fertiliser, it has been the preferred fertiliser in recent years. The lower solubility should lessen the risk of toxicity and help extend the period of effectiveness.

Perhaps more than with other fertilisers, accurate application of this potentially toxic trace element is essential. The most effective method to achieve uniform spread has proved to be the use of a helicopter fitted with an electronic guidance system.

7. COPPER AND ZINC DEFICIENCIES IN RADIATA PINE

Introduction

The first micro-nutrient deficiency to be recognised in New Zealand plantations was that of boron, and it remains the most widespread. However, smaller areas of both copper (Cu) and zinc (Zn) deficiencies have been found.

Severe twisting of branches and main stems in 6-year-old trees was observed in Mangawhai Forest near Whangarei in the late 1960s. This was shown to be caused by copper deficiency. Localised pockets of copper deficiency have also been found at Aupouri, another sand dune forest in Northland. In the same part of the country, plantations on much older podzolised sands can also become copper-deficient.

For many years zinc deficiency has been known to occur in some Australian plantations and severely affect their growth. It was not until 1984 that the first zinc-deficient trees were recognised in New Zealand plantations.

Identification of Copper Deficiency

Visual symptoms

Twisting of branches and the main leader are characteristic of copper deficiency (Fig.1). Where only slight twisting is present, branch growth may be more horizontal (Fig.2). In severe deficiency, twists in the leader cause it to have a more horizontal than vertical growth habit (Fig.3).

FIG.1 Twisting of leader and branches of radiata pine caused by copper deficiency.

FIG.2 Mild copper deficiency in radiata pine. Note flat branch angle and some branch twisting.

There are no characteristic foliage symptoms, but fused needles and needle-tip burn have been found on some copper-deficient sites.

Other causes of similar symptoms

Reports from Australia associate branch twisting with both potassium and boron deficiencies but these have not been seen under New Zealand conditions. Boron deficiency does result in dead shoots being bent into an inverted U or J but this is completely different to the twisting of live stems in copper-deficient trees.

Wind and rain can cause more twisting than is generally realised. Several days of strong wind from one direction can cause soft spring growth to take on a permanent bend, and the weight of wet foliage can accentuate the degree of bending. Twisting by wind and rain can usually be recognised by its uniform pattern. Similar-aged shoots on a tree and on adjacent trees are twisted in the same direction to about the same extent (Fig.4).

On individual trees possums climbing in the top of the crown can bend branches in one or more whorls into a more horizontal position.

Some herbicides cause branch twisting. This is often, but not always, associated with chlorosis in the foliage and/or characteristic thickening of the end of the stem. While copper deficiency can usually be seen to have caused twisting in several successive years, herbicide twisting is a single event producing moderate to severe symptoms in previously unaffected trees.

Foliage analyses

Noticeable twisting of branches is associated with foliage levels of less than 1–2 ppm Cu.

Occurrence of Copper Deficiency in New Zealand

Copper deficiency occurs in forests on recent coastal sands in Northland – particularly in Mangawhai Forest on the east coast, but also in parts of Aupouri Forest on the west coast (Fig.5). On older podzolised soils in Northland tree growth is often poor. By ripping and bedding, and the application of nitrogen and phosphate fertilisers, tree growth is increased greatly. Under these circumstances copper deficiency can develop. Examples are Waipoua Forest and Whitecliffe's Forest at Utakura.

Twisting associated with low levels of copper has also been recorded on pakihi soil near Westport.

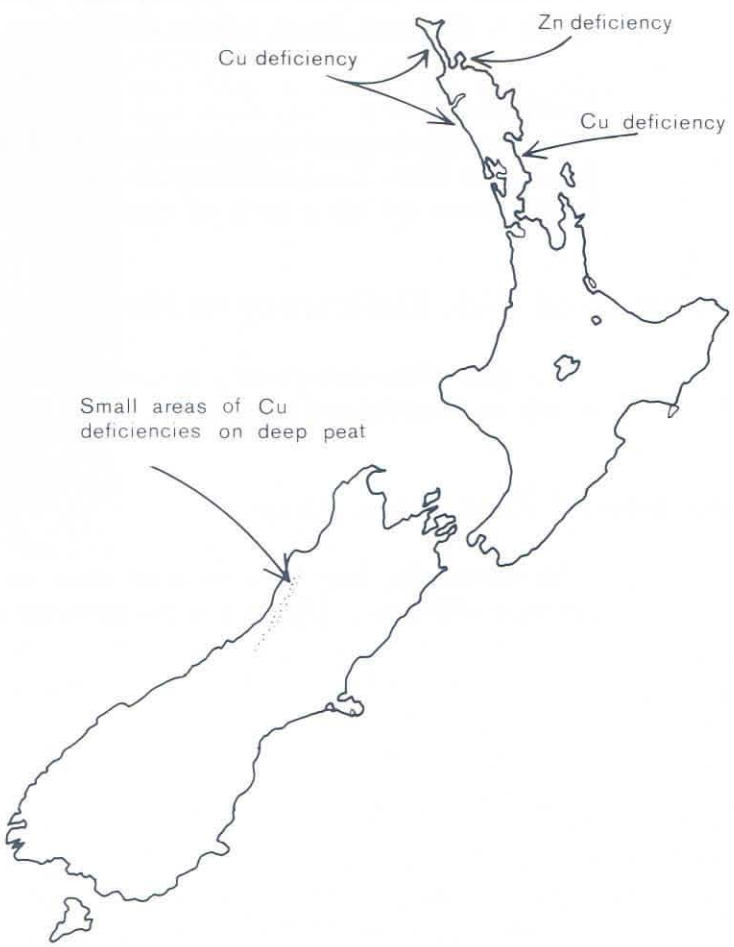
Correction of Copper Deficiency

Applications of copper at rates of 7–10 kg Cu/ha have proved successful in correcting severe symptoms. In trials, this has been applied as bluestone (copper sulphate). On a management scale, Mangawhai Forest was sprayed with copper oxychloride, as used for Dothistroma control. If other fertilisers, such as nitrogen and phosphate, are being applied to a site where copper deficiency is a possibility, copper should be included in the mix so as to apply 5 kg Cu/ha.

FIG.3 Severe copper deficiency in radiata pine. Note marked twisting of branches and leader, resulting in loss of upright growing habit. (CS 28226)

FIG.4 Branch and leader bending caused by 3–4 days of high winds in December. Photograph taken after wind had abated. As tree corrects growth to vertical a bend will remain in most shoots.

FIG.5 Major areas of copper and zinc deficiencies in New Zealand forests.



Identification of Zinc Deficiency

Visual symptoms

Growth is stunted in young trees, producing a rosette of buds around the terminal. Needles are short and have dead tips (Fig.6). From Australian experience these growth disturbances in young trees give rise to severe malformation caused by multileaders.

FIG.6 Rosette of retarded buds caused by zinc deficiency. (CS 37846)

Other causes of similar symptoms

Rosettes of buds appear to be specific to zinc deficiency. In New Zealand, however, multileader-type malformation is associated with a number of causes: a major cause is "retarded" leader, whose incidence increases on very fertile sites (high nitrogen in particular); and another cause is dieback from boron deficiency.

Foliage analyses

Severe symptoms are associated with foliage zinc less than 5 ppm. Most forests in New Zealand have 30–50 ppm Zn, and 10 ppm appears to be a level below which a lack of zinc may affect growth.

Occurrence of Zinc Deficiency in New Zealand

To date zinc deficiency is restricted to one or two specific sites in the north of Northland (Fig.5).

Correction of Zinc Deficiency

In Australia, low amounts of zinc in a foliage spray or fertiliser have proved effective. There are no proven results in New Zealand as yet.

8. MANGANESE (AND IRON) DEFICIENCY IN RADIATA PINE

Throughout New Zealand, there are small areas of soils formed from limestone. Where soil development has proceeded to some depth and the effects of climate and vegetation have modified the alkaline (high pH) nature of the parent rock, tree growth is relatively normal. Where the soil is shallow, close to limestone outcrops or where erosion has removed topsoil, radiata pine growth can be restricted and the foliage can become quite chlorotic.

Because this is a very localised problem in only a few plantations, no detailed studies have been carried out. However, from foliage analyses it does seem that manganese uptake is restricted on these alkaline soils. Also, although total iron levels in the foliage are not particularly low, work with other plant species in similar soils suggests that the fraction of active iron in the plant may be inadequate.

Older foliage is a pale yellowish green, particularly on needle tips. The most characteristic feature is the very pale yellow colour of immature current season's foliage (Fig.1). Typical levels of manganese in the foliage of affected trees are 3–6 ppm.

Affected, deficient trees can be expected wherever limestone, at or near the soil's surface, creates alkaline conditions. A similar condition is described in Section 9 where limestone dust created alkaline conditions in a nursery soil. In the affected nursery, it was possible to correct the position by acidifying the soil using heavy applications of sulphur. It is most unlikely in plantations that there is any economic way of correcting the condition. Effective acidification would not be practical and an application of manganese (and iron) is unlikely to have any lasting effect in such an alkaline soil.

In South Africa where true manganese deficiency exists (in contrast to low manganese availability in an alkaline soil) fertiliser applications are effective.

FIG.1 Chlorosis of foliage of young radiata growing on a limestone soil. Note very pale colour of young foliage.

9. NUTRIENT DEFICIENCIES IN RADIATA PINE SEEDLINGS

Introduction

A balanced fertiliser programme is essential in every nursery. For optimum establishment and growth in the field, seedlings must leave the nursery in top nutrient condition, with as high a nutrient status as is compatible with balanced root-shoot growth and adequate conditioning.

Forest nurseries are an intensive form of land use and the annual nutrient removal in crops of whole seedlings (roots and shoots) is high. A soundly based fertiliser programme is essential to maintain soil fertility and nursery productivity. Soil tests and past experience should be used each year to determine quantities of fertiliser to be applied as a base dressing before seed sowing. Superphosphate, dolomite, and muriate of potash (potassium chloride) are most commonly used in amendments for base dressings.

Several light side-dressings of a balanced multi-nutrient (N, P, K, Mg) fertiliser should be applied during the growing season to meet the requirements of the seedlings. Past experience, including soil and foliage analyses and seedling appearance, should be used to determine the quantities of and balance between N, P, K, Mg, etc. Prevention is always better than a cure. Slight symptoms call for a soluble fertiliser application as soon as possible. Correction of more severe symptoms may be best accomplished by an additional emergency foliage spray. The first effect of any nutrient deficiency is to slow growth. Then with mobile nutrients, such as magnesium, the first signs of nutrient stress are seen in the older foliage. Immobile nutrients, like iron, first cause stress in the youngest foliage.

Nitrogen deficiency

Some degree of nitrogen stress is likely to occur in most nurseries in most years. Symptoms are a yellowish green colour to the foliage. Discoloration is even along the length of individual needles, and varies little over the whole seedling (Fig.1). In moderately affected seedlings, needle length is shorter, and diameter and branch development tend to be restricted more than height growth (Fig.2).

FIG.1 Nitrogen stress in radiata pine seedlings – seedlings in bed in the foreground are under greater stress than those in the background. Note even coloration over all foliage in stressed seedlings, which did not receive usual side-dressing during the growing season. (CS 39001)

FIG.2 Seedlings from an experiment in which a range of levels of nitrogen were supplied. Note how colour differences are noticeable only after considerable decreases in growth rate have occurred.

Phosphorus deficiency

This deficiency is uncommon in developed nurseries. With slight to moderate deficiency, there is a general reduction in growth and perhaps bluish green needles but no other particularly obvious visual symptoms. In acutely deficient seedlings, the apical tuft of foliage consists of short slightly yellow-tipped needles which tend to curve upwards and inwards towards the apical bud giving the top of seedlings a flat appearance (Fig. 3).

In new nurseries that are being developed and growing their initial crop of pines, phosphorus deficiency symptoms are often associated with localised absence of mycorrhizal development.

FIG.3 Levels of phosphorus stress in radiata pine seedlings. Note marked differences in growth but similar foliage colour with all, except extreme, deficiency. The latter is most unlikely to be encountered in practice. Some of the deficient seedlings have developed "flat tops". (CS 29622)

Magnesium deficiency

This deficiency is quite common, particularly in pumice-soil nurseries. It has been the most spectacular of the nutrient deficiencies seen in New Zealand nurseries (Fig.4). Growth is decreased and the tips of needles become a golden yellow while the remaining length is a normal green. When the deficiency is more severe, a greater length of each needle is affected, and the needle tips may die (Fig.5). Magnesium availability and/or uptake is restricted in strongly acid soils, cold and wet soils, and those high in available potassium and nitrogen.

FIG.4 Extreme magnesium deficiency in radiata pine seedlings. Note complete recovery of seedlings in plot in foreground treated with magnesium sulphate (Epsom salts) 3 months earlier. (CS 6449)

FIG.5 Magnesium deficiency. Note golden yellow tips to needles with over half the needle length affected on the centre seedlings. (CS 34505)

Potassium deficiency

Stunted growth caused by acute potassium deficiency is rare in New Zealand nurseries. Needles show yellowish coloration. This is more pronounced on the tips of needles (in contrast to nitrogen deficiency) but not entirely absent from the remaining length of needles (in contrast to magnesium deficiency). Reduced growth in otherwise apparently healthy seedlings is probably more common.

Iron deficiency

Occasionally, young seedlings (3–5 cm) develop a pale greenish yellow colour in the tuft of terminal needles (Fig.6). Available evidence suggests that this is caused by a temporary immobilisation of iron in the soil. This usually corrects itself within a few weeks and seedlings regain normal colour. Causes can include excessive amounts of phosphate in acid soils. The application of foliage sprays of iron chelates can counteract unfavourable soil conditions.

In one nursery at Pakipaki near Hastings, iron (and manganese?) nutrition was disturbed by the induced calcareous nature of the soil (Fig.7). The resulting lime-induced chlorosis was successfully corrected by acidifying the soil with elemental sulphur.

FIG.6 Iron deficiency in young radiata pine seedling. Note pale yellowish terminal foliage of seedling second from right. (CS 37763)

FIG.7 Lime-induced chlorosis in radiata pine seedlings from Pakipaki nursery. On right, stunted chlorotic seedlings; on left, healthy seedlings in soil treated with sulphur. (CS 14874)

Copper and zinc deficiencies

In Sweetwater Nursery established on peat near Kaitaia, heavy applications of lime appeared to cause a localised reduction in the availability of zinc. On another occasion, more widespread severe copper deficiency symptoms developed in seedlings.

Copper deficiency causes a marked drooping of needles in the apical tuft: needle tips die back to a uniform degree (Fig.8).

Zinc deficiency causes a stunting of growth and the development of a rosette of buds in place of the usual single terminal bud (Fig.9). Foliage may assume a bronze colour.

FIG.8 Copper deficiency in radiata pine seedlings. Three seedlings on left are deficient. Note drooping needles with necrotic tips. (CS 11149)

FIG.9 Zinc deficiency in radiata pine seedlings. Seedlings on right zinc deficient; those on left have been treated with a zinc foliage spray and new growth is evident from previous rosette of buds. (CS 11140)

10. NUTRIENT DEFICIENCIES IN *EUCALYPTUS* SPECIES

Introduction

For many years *Eucalyptus* spp. have been planted in nearly all parts of New Zealand but until recently most plantings were in farm shelterbelts, woodlots, or small-scale plantations. Since about 1970 private industry has established larger plantations to create a resource of short-fibre pulp wood, and the New Zealand Forest Service has included eucalypts as a major part of its programme to plant significant areas of special purpose timbers.

The vigour and uniformity of tree growth in many of the new plantations are not as good as expected. It has become apparent that establishment practices adequate for radiata pine are not good enough for eucalypts. In particular, there are three areas where eucalypts have special requirements.

(i) Eucalypts are very sensitive to nitrogen deficiency, and their need for phosphorus has often been underestimated in the past.

(ii) Soil physical conditions can be all important (Fig.1). Eucalypts grow best in a deep friable soil. This is well illustrated by the better growth which is often seen in roadside trees growing on disturbed soil; even though side-castings may not be nutrient-rich (little topsoil present), the best trees are often found there. Restricted rooting volume appears to markedly accentuate any soil deficiencies.

(iii) In the early years at least, growth in eucalypt plantations is very sensitive to weed competition. For instance, grass or fern competition can cause almost complete stagnation of tree growth. Competition for nutrients and moisture are major factors involved (Fig.1).

South Africa has some of the largest eucalypt plantations in the world, and they have developed establishment techniques that promote very fast and uniform growth on a range of sites. In the past we, in New Zealand, have been far from achieving a similar degree of success in our plantations. *Eucalyptus grandis* is the major species grown in South Africa but there is no reason to believe that the species grown in New Zealand have very different requirements.

South African experience and practice has been summarised, "Fertilisation cannot be regarded as a remedy for poor site preparation (cultivation, ripping where needed, and weed control) nor good site preparation as an excuse not to fertilise". Translated to the New Zealand scene this means that:

(i) Discing, ripping and bedding, 'V' blading, or some form of cultivation is needed on most sites to give an adequate volume of loose soil.

(ii) Weed control is needed on almost all sites and absolutely essential if grass is present.

(iii) Fertile farmlands being converted to plantations are the only areas where fertilisers may not be required.

The main species grown in New Zealand are *Eucalyptus regnans, E. saligna, E. delegatensis,* and *E. fastigata.* They do not all react to nutrient deficiencies

FIG.1 The effects of soil compaction, nutrition, and weed competition on the growth of eucalypts. Left foreground – nitrogen deficient trees on compacted soil of old skid site from which topsoil had been removed. Right foreground – healthy vigorous trees on area where topsoil from skid site had been dumped. In the background is undisturbed soil but vigorous bracken competition – note poor survival and nitrogen deficiency symptoms. (CT 2308)

in exactly the same way, but, until current research provides more specific details for individual species and nutrients, the following general descriptions will be useful. It must be remembered that both weed competition and inadequate cultivation are avoidable causes of nutrient deficiencies that are not easily remedied by the application of fertilisers.

Deficiency Identification

Nitrogen deficiency

Greenish yellow, yellow-orange, or red foliage depending on species and severity of deficiency. Petioles and bark on twigs also show similar or even more intense discoloration (Fig.1 and 2).

Phosphorus deficiency

Purple discoloration of foliage (Fig.3).

FIG.2 Orange-red foliage discoloration of nitrogen-deficient Eucalyptus saligna *seedlings.* (CS 38997)

FIG.3 Purple foliage colour caused by phosphorus deficiency. Eucalyptus saligna, *Tairua Forest.*

The symptoms of nitrogen and phosphorus deficiencies occur in full-sized leaves and are not be be confused with the shades of green that are present in healthy immature foliage. There is a tendency for nutrient deficiency symptoms to be most marked near the base of the crown but there are exceptions to this, particularly when the deficiency has caused all but a small amount of foliage to be shed.

Vigorous growth of nursery seedlings and young trees in the field is associated with foliage levels of about 2.0% N and 0.15% P.

Eucalypts can be self-pruning and, in general, even open-grown trees do not maintain a green crown to ground level. However, young healthy trees should reach a height of at least 4–6 m before branches at ground level lose foliage. If trees of smaller size do not have healthy foliage right to the ground, it is an indication that either:

(i) there has been adverse weed competition causing suppression of the lower crown, or

(ii) the tree is nutrient-deficient.

Under conditions of nutrient stress, several nutrients including nitrogen and phosphorus can be withdrawn from leaves in the lower crown and recycled to the growing points in the upper crown. Following substantial nutrient withdrawal, foliage in the lower crown is then shed. In extreme cases, trees of only 3 m in height may have lost all foliage below a height of 2 m (Fig.4 and 5).

Trees in the same stand, and even foliage on the same tree, often show varying degrees of combinations of nitrogen and phosphorus deficiencies.

Boron deficiency

Dieback of young shoots in the top of the crown.

Iron deficiency

Distinct interveinal chlorosis.

FIG.4 Severely nutrient-deficient Eucalyptus delegatensis *growing on compact soil on old firebreak.* (CT 2309)

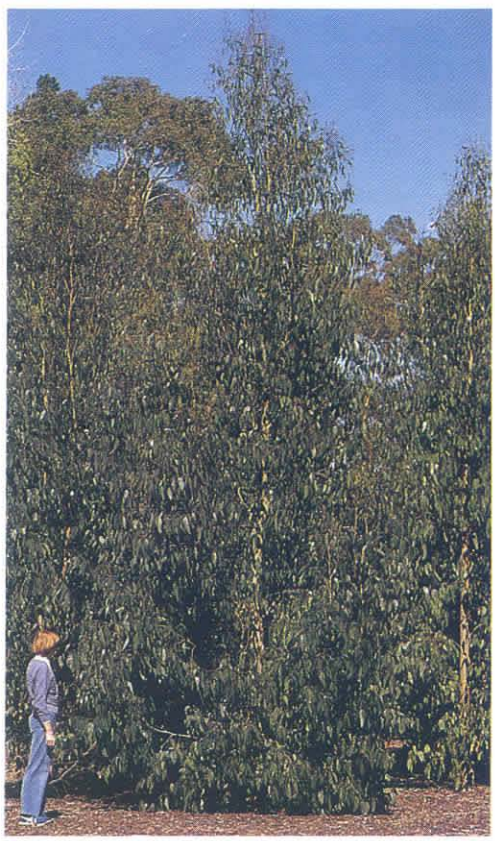


FIG.5 Deep uniformly green crowns of Eucalyptus regnans *growing under adequate nutrient supply.* (CS 40008)

Occurrence of Deficiencies in New Zealand

Nitrogen deficiency
Common in nurseries particularly in potted stock. It is characteristic of seedlings being held in plantable conditions for extended periods by stopping fertiliser applications. Some degree of deficiency exists in almost all forests – particularly in young stands.

Phosphorus deficiency
Marked in those forests on soils where phosphate is routinely applied to radiata pine. Some degree of deficiency is likely in many forests particularly where topsoil has been removed.

Boron deficiency
Confirmed deficiency so far confined to stands in Nelson region.

Iron deficiency
Common in nurseries, particularly in potted stock.

Correction of Deficiencies by Fertilisers

Nitrogen
Slow-acting fertilisers such as Magamp or IBDU are ideal for nursery beds (Magamp 250 kg/ha; IBDU 250–500 kg/ha) or potting mixes (Magamp up to 4.5 kg/m^3).

In the field 60 g of urea per tree soon after planting is standard for pumice soils. Where phosphorus deficiency is at all likely, 90 g of DAP should be applied.

Few data are available for older stands but N.Z. Forest Products Ltd have found 250 kg urea/ha an effective rate to apply at age 1 or 2 years to stands on pumice soils.

Phosphorus
DAP at the rate of 90 g/tree soon after planting is recommended. This is because almost without exception any site deficient in phosphorus will give some response to nitrogen. The requirements of older stands have not been determined.

Boron
No information is available, but 4–8 kg B/ha as for radiata pine is suggested.

Iron
Standard and effective treatment is to apply iron chelate (Fe EDTA) in solution. In nursery beds, 500 *l*/ha 0.1% solution should be applied and potted stock should be watered with a solution of 2 g in 10 *l*.

11. FOLIAGE SAMPLING AND NUTRIENT ANALYSIS OF RADIATA PINE

Like all other plants, trees require a minimum supply of each nutrient to be healthy and maintain growth. The concentration of a nutrient in foliage is a good indication of the supply available. Over a number of years, foliage samples have been taken for analysis from healthy trees and others affected to various degrees by a range of nutrient deficiencies. Using these data, it is now possible to analyse foliage and determine which, if any, nutrient is deficient and the degree of deficiency.

Where a deficiency is suspected, a foliage sample should be taken from a group of trees that all show similar visual symptoms. When a sample is taken as a preliminary to possible routine fertiliser application, foliage should be collected over an area that forms a management unit with similar age, vigour, and fertiliser history. Vigour may often vary with position on the landscape, i.e., ridge top, mid slope, and valley bottom. These should then form separate sampling units.

Details of how to take a foliage sample can be best described by answering the following questions:

When should sampling be done?
Nutrient deficiencies can usually be recognised in samples taken at any time of the year but samples for advisory recommendations for fertiliser use must be taken in late February-March. This is the time of maximum stress and a period over which nutrient concentrations are relatively stable.

What age of foliage should be sampled?
Current season's foliage that has reached mature length.

Where in the crown should it be taken from?
Second-order branches in the top third of the crown, well above the point where competition for space by adjacent trees causes any suppression of growth or undue shading (Fig.1). Sample at least two branches per tree.

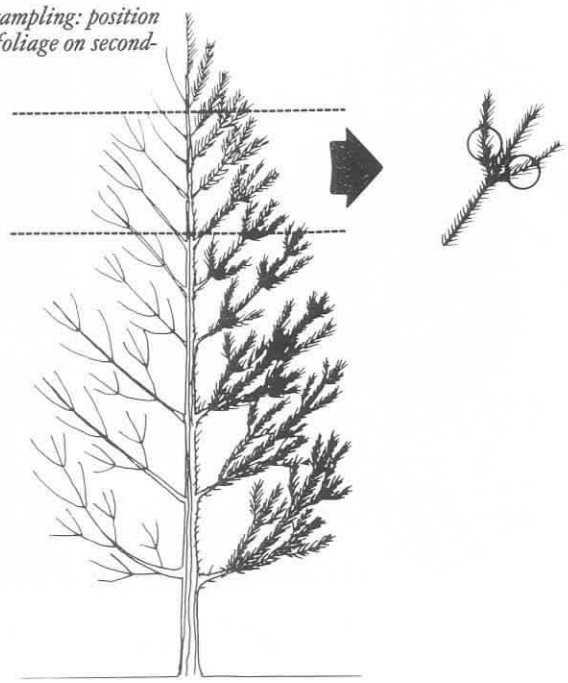


FIG.1 Diagrammatic guide to foliage sampling: position in top crown (left); and mature length foliage on second-order shoots (right).

How many trees should be sampled?
Acute deficiencies can usually be identified by combining foliage from just a few trees. However, in accurately assessing the nutrient status of a stand, the effects of tree-to-tree variation should be minimised by sampling foliage from 10, and preferably 15–20 trees. Where soil fertility gradients may be present within a stand, more intensive sampling can be required as the basis for fertiliser recommendations. Current practice in one forest is to take 5–20 composite foliage samples, depending on the size of the management unit to be topdressed, with each composite sample taken from five trees.

Which trees in a stand should be sampled?
Only dominants and co-dominants.

How much foliage is needed?
A total of a "good fistful" of needles per sampling unit. This may mean only a few fascicles per tree. Be sure to collect the same amount from each tree.

THUS – A GOOD FISTFUL OF CURRENT SEASON'S FULL-LENGTH FOLIAGE TAKEN IN MARCH FROM SECOND-ORDER BRANCHES IN THE TOP THIRD OF THE CROWNS OF A REPRESENTATIVE SAMPLE OF TREES.

How are samples collected?
(a) By hand from the ground with young trees (Fig.2) or by climbing into the crown with older trees.
(b) By pole-mounted cutters with trees up to 8–10 m (Fig.3)
(c) By shotgun (older trees). Use a shotgun with a tight choke and make sure that the foliage which is collected is what was aimed at.
(d) By helicopter. A recent innovation in Nelson Conservancy.

FIG.2 & 3 Foliage sampling of young trees (left) by hand and older trees (right) by pole-mounted cutters.
(CN 11503 & CN 11459)

How should samples be handled?
Each sample must be kept as clean and dry as possible (collection during or after rain is not advised); after packing in a new plastic bag together with a label, samples should be kept out of the sun and as cool as possible. If more than a fistful is collected in the field, mix thoroughly and subsample before placing in plastic bag. If the samples cannot be sent to the laboratory the same day, they should be stored in a fridge. Despatch to the laboratory should be as soon as possible by the fastest transport available.

Interpretation of Results

Total concentrations of one or more nutrients are measured in the laboratory and then can be related to the following standard values.

Foliage analysis values for Pinus Radiata

Nutrient	Low <	Marginal	Satisfactory >	Confidence Rating
		%		
N	1.2	1.2 - 1.5	1.5	**
P	0.12	0.12–0.14	0.14	***
K	0.30	0.30–0.50	0.50	**
Ca	0.10	0.10	0.10	*
Mg	0.07	0.07–0.10	0.10	**
		ppm		
B	8	8–12	12	**
Cu	2	2–4	4	**
Zn	10	10–20	20	*
Mn	10	10–20?	20?	*

*** Good prediction of responsive sites in both the low and marginal range.

** Good prediction of responsive sites in the low range but not in the marginal range.

* Insufficient information and experience to confidently predict a response even in the low range (values based mainly on overseas experience).

NOTES